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# Pollution Abatement from Cattle Feedlots in Northeastern Colorado and Nebraska

National Environmental Research Center
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# POLLUTION ABATEMENT FROM CATTLE FEEDLOTS IN NORTHEASTERN COLORADO AND NEBRASKA

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# ABSTRACT

Climatic factors, feedlot runoff, and organic material in the runoff were evaluated in experimental and commercial feedlots. The effects of slope, stocking rates, terraces, basins, and holding ponds were evaluated to obtain the best controls for containing runoff. In eastern Nebraska, 70 cm annual precipitation produces 23 cm of runoff; whereas, in northeastern Colorado, 37 cm annual precipitation gives only 5.5 cm of runoff. Large applications of runoff liquid, up to 91 cm on grass-Ladino and 76 cm on corn, in Nebraska did not decrease yields; however, in northeastern Colorado, the concentrated high-salt runoff required dilution before direct application to crops. The organic manure-soil interface severely restricts the movement of water, nitrates, organic substances, and air into the soil beneath feedlots. The amounts of $NO_3$-N in soil cores taken from Nebraska feedlots and croplands ranked as follows: abandoned feedlots > feedlot cropland > upland feedlots > river valley feedlots > manure mounds > alfalfa > grassland. Feedlots contribute $NH_3$, amines, carbonyl sulfide, $H_2S$, and other unidentified substances to the atmosphere. Ammonia and amine can be scavenged from the air by green plants and water bodies. Anaerobic conditions in feedlots are conducive to the production of carbonyl sulfide, $H_2S$, and amines. Management practices, such as good drainage, that enhance aeration will decrease the evolution of these compounds.

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# PREFACE

This report summarizes research findings and fulfills all the requirements of the Interagency Agreement EPA-IAG-D4-0446 between the U. S. Department of Agriculture, Agricultural Research Service and the Environmental Protection Agency, covering the 4½-year period ending June 30, 1974, and involving a jointly-financed research program and plan of operation as set forth in the proposal "Pollution abatement from cattle feedlots in Northeastern Colorado and Eastern Nebraska" submitted by Dr. C. E. Evans, ARS, Fort Collins, Colorado, on May 9, 1969, and as amended June 27, 1972. The overall research objectives were:

1. To determine the extent and kinds of microbial, chemical and organic pollutants entering the atmosphere, soils, and surface and underground water supplies from cattle feedlots in two contrasting climatic zones (Northeastern Colorado with annual precipitation of 14-15 inches and Eastern Nebraska with annual precipitation of 27-28 inches); and

2. To evaluate different feedlot management systems as to their effectiveness and efficiency in disposing of both liquid and solid wastes under two different climatic conditions.

This research program was conducted under a memorandum of agreement (Grant 13040 DPS) between the Federal Water Pollution Control Administration (a predecessor of EPA) and ARS during Fiscal Years 1970 and 1971, and under interagency agreements EPA-IAG-0200(D) in FY 1972, EPA-IAG-135(D) in FY 1973, and EPA-IAG-D4-0446 in FY 1974.

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# SECTION I

## INTRODUCTION

This report is a summary of cooperative investigations made January, 1970, through June 30, 1974, between the Agricultural Research Service and the Nebraska and Colorado State Agricultural Experiment Stations with the financial support of the Environmental Protection Agency. Many of the studies have not been completed, and therefore, only progress reports are given. Many parts of the investigations have been completed, and the methodology and results are reported in the papers listed in the List of Publications.

The research was conducted at various field sites in central and eastern Nebraska and in northcentral Colorado and in Agricultural Research Service Laboratories at Lincoln, Nebraska, and Fort Collins, Colorado.

THE SPECIFIC OBJECTIVES OF THE RESEARCH WERE:

(1) To determine the extent and kinds of microbial, chemical, and organic pollutants entering the atmosphere, soils, and surface and underground water supplies from cattle feedlots in two contrasting climatic zones (northeastern Colorado, with annual precipitation of 35.6 to 38.1 cm (14 to 15 in.), and eastern Nebraska, with annual precipitation of 68.6 to 71.1 cm (27 to 28 in.).

(2) To evaluate different feedlot management systems as to their effectiveness and efficiency in disposing of both liquid and solid wastes under two different climatic conditions.

Although the two areas have similar moderate temperature regimes, markedly differing precipitation permits comparison of precipitation differences on runoff, percolation, and profile aeration on otherwise similar conditions. In both areas, cattle are usually fed on earth-surfaced lots at comparable rates of stocking. The Nebraska research sites are in the zone classed as dry by EPA, with a 25- to 75-cm (9.8 to 29.5 in.) annual deficit of potential evaporation over precipitation. The Colorado field sites are in the semiarid zone, with a deficit exceeding 75 cm (29.5 in.).

# SECTION II

## SUMMARY

Two climatic zones (northeastern Colorado, precipitation 35.6 to 38 cm, and eastern Nebraska, precipitation 68 to 71 cm) were selected to study the effect of climate, feedlot animal density, feedlot design, and feedlot management on the extent and movement of potential air and water pollutants from feedlots. The extent of water percolation and inorganic and organic chemicals movement beneath feedlot soil surfaces was studied with specially constructed caissons and vacuum lysimeters. Climatic factors were monitored with rain gages, anemometers, hydrothermographs, evaporation pans, and maximum and minimum thermometers. Detention basins were constructed to retain runoff and equipped with water-level recorders to record the duration, rate, and quantity of runoff.

In eastern Nebraska, 70 cm (27 inches) of annual precipitation produces 23 cm (9 inches) of runoff, whereas in northeastern Colorado, 37 cm (14.5 in.) annual precipitation produces only 5.5 cm (2.2 in.) of runoff. The runoff in Colorado is highly concentrated, especially in salts, and should not be applied directly to crops. In Nebraska, large applications of feedlot runoff have been applied directly to crops--up to 91 cm (36 in.) on grass-Ladino and 76 cm (30 in.) on corn--without adverse effects. In eastern Nebraska, feedlots should be designed to control runoff and materials that can be transported by surface water. This can be accomplished by controlling the degree and length of slope in feedlots and utilizing diversion terraces and debris basins. For sloping feedlots, the degree and length of slope should not exceed by more than three times that recommended for cropland. Terraces and mounds can be employed to restrict length of slope and improve drainage. Basins can be used to collect runoff from feedlots. Solid accumulation in a basin should not exceed 20 cm (7.8 in.) before removal. Accumulations of feedlot solids greater than 20 cm results in long drying times and odor problems. The organic solids in runoff effluent effectively seal the soil surface of basins, preventing water infiltration.

Data collected for water percolation and movement of nitrate and organic pollutants beneath feedlots indicate that if the feedlot is kept continuously stocked so as to maintain an intact manure layer, there is little likelihood of nitrate or other pollutants moving through the soil profile to the water table. An anaerobic layer develops at the interface of the manure and the soil. This interface helps prevent the movement of nitrate and water. Caution should be exercised in cleaning operations not to destroy this interface layer. Abandoned feedlots contained more nitrate-N in their profile than under any other conditions studied. In a 9.1-meter (29 ft) profile,

there was 7.2 metric tons of $NO_3$-N per hectare (3.2 tons/acre). This was almost 3.5 times the quantity of $NO_3$-N accumulated under any other management system. Feedlots which were abandoned and then cropped showed some decrease in $NO_3$-N levels. Both corn and alfalfa took up significant amounts of nitrate from abandoned feedlots. Nitrate analyses of corn plant materials showed high levels of $NO_3$-N.

Beef cattle feedlots can contribute significant amounts of ammonia, amines, and odiferous sulfur compounds to the atmosphere. Such compounds are potential pollutants to water surfaces and life (plant and animal) in the vicinity of the feedlot. Ammonia and amines were trapped in acid. Traps, fabricated of wire mesh with a conical metal roof and a plywood floor, were placed 1.5 m (4.9 ft) above the ground on posts. Plastic dishes (750 ml) filled with 0.01 N $H_2SO_4$ were placed inside the trap. This solution was changed every 1 to 3 weeks, depending on evaporation, and analyzed for distillable N (ammonia and short-chained amines). Amines and sulfur compounds were analyzed by gas chromatography and colorimetric techniques. Significant amounts of the basic N-compounds volatilized were aliphatic amines.

Aliphatic amines have the potential for altering metabolism and thus could affect water ecosystems. Chemical theory and observations suggested that gaseous aliphatic amines can be absorbed by water exposed to low atmospheric concentrations of the compounds. Microorganisms were found in lakes that degrade aliphatic amines, and during warm weather microbial activity was sufficient to inhibit amine accumulation. The effect of various concentrations of aliphatic amines on algal metabolism was studied. Algae could not utilize amine-N for growth. Algal photosynthesis is hindered while respiration is enhanced by methyl amine.

Our research showed that significant amounts of $NH_3$ volatilized from the surface of cattle feedlots and was absorbed by water, soil, and plant surfaces in the vicinity of a feedlot. Foliar $NH_3$ absorption occurs readily and the data suggest it plays an important role in decontaminating the earth's atmosphere. Calculations based on plant $NH_3$ absorption rates showed that at normal atmospheric concentrations of $NH_3$, plant canopies could absorb 20 kg N per hectare (17.8 lb N per acre) per year.

# SECTION III

# CONCLUSIONS

## COMPOSITION AND AMOUNT OF RUNOFF INCLUDING CLIMATIC VARIABLES, SLOPE, STOCKING DENSITY, SITE, AND SITE MODIFICATION

About 5 cm (2 in.) of runoff is expected annually from feedlots in the 35-cm (13.8 in.) precipitation area of northeastern Colorado. At the study site, the manure pack consistently absorbed the first 1 cm (.4 in.) of precipitation, with an average of 45 percent of the precipitation above 1 cm leaving the lot as surface runoff. Because the studies at Fort Collins were limited to a single site and relatively few runoff-producing events were recorded during the study period, it is difficult to establish, with confidence, the expected range of annual runoff. Over the three years of record, runoff varied from less than 1 to 25 percent of the annual precipitation, depending upon distribution and intensity of precipitation. Above 23 cm (9 in.) of runoff is expected from the 70-cm (27.6 in.) annual precipitation in eastern Nebraska. However, the precipitation over a period of years will vary from less than 50 cm (19.7 in.) to over 85 cm (33.5 in.) and annual runoff from a feedlot may vary from less than 15 cm to 35 cm (5.9 to 13.8 in.). Design of control structures should be based upon the chronic wet periods of continuing wet weather that may be expected over a 10-year period.

Pollution by runoff transport of materials from beef cattle feedlots can be accomplished best by: (1) control of the degree and length of slope factor utilizing diversions and terraces; (2) use of debris basins or solids traps to immediately separate readily settleable solids from the effluent to eliminate problems of combined storage of the solids and effluent; and (3) disposal of the solids and the effluent on cropland.

## DISPOSAL OF RUNOFF

In eastern Nebraska, feedlot runoff effluent is a highly variable, low-grade fertilizer. However, large and frequent applications can supply much of the nutrient needs of many crops. Annual applications up to 91 cm (35.8 in.) on grass-Ladino clover and 76 cm (29.9 in.) on corn have not decreased and sometimes have increased yields. Good growth of the Ladino clover, a low-salt-tolerance crop, indicates salt accumulation in the soil is not a problem.

Under northeastern Colorado conditions, the infrequent and very limited runoff is of such concentrated composition that direct application to growing crops would not be feasible. Disposal on arable land would be possible after sufficient dilution with irrigation water to reduce the electrical conductivity to values acceptable for irrigation water.

## COMPOSITION OF SOIL SOLUTION AND SOIL ATMOSPHERE BENEATH FEEDLOTS

There was no marked movement of organic substances into the feedlot as would be shown by increases in COD and $PO_4^{3-}$. This conclusion is in agreement with a previously published report of Mosier et al. (1). These authors concluded that there was no uniform or continuing movement of organic compounds from the manure pack either into subjacent soil profile or through that profile into the groundwater. Nitrate and other soluble nitrogen-containing pollutants will percolate only a short distance downward from the lot surface in a continuously stocked feedlot. Significant percolation of water was detected only at the flat site near Fort Collins, and then only immediately following thorough scraping of the surface or significant drying of the surface manure pack. Most physical characteristics of the feedlot interface severely restrict movement of air and water into the soil. Microbial metabolism of organic matter near the feedlot surface further depletes the oxygen supply. This results in reduced conditions in the feedlot soil profile which is favorable for denitrification. If a new feedlot is stocked continuously, initial nitrate buildup will decrease, presumably due to denitrification. In areas where denitrification occurs, there is usually a buildup of methane in the soil profile beneath the feedlot. Areas of the feedlot which do not contain methane in the profile may contain appreciable $NO_3$-N.

The management of feedlots is an important consideration to the accumulation of $NO_3$-N in the soil profile and care must be exercised to leave the interface layer intact when the feedlot is cleaned. Feedlots should not be allowed to lie idle for long periods of time.

The $NO_3$-N content of soil profiles from abandoned feedlots, feedlot-cropland, etc., were examined and ranked according to decreasing average $NO_3$-N in the soil cores: abandoned feedlots > feedlot-cropland > upland feedlot > river-valley feedlots > manure mounds > alfalfa grassland. Feedlots continuously stocked, under mounds, and flat river-valley feedlots do not have problems with $NO_3$-N accumulation in the soil profile and would not likely contribute nitrate to the groundwater. A feedlot site that was abandoned for feeding and left idle for 6 years contained more than 19 metric tons (20.9 tons) of $NO_3$-N per hectare to a soil depth of 9 meters (9.8 yd). Another feedlot site that was abandoned and cropped to alfalfa and corn for about 14 years showed $NO_3$-N content similar to cropland.

## INVESTIGATIONS ON METHODS OF EXTRACTION OF NITRATE FROM THE SOIL PROFILES OF ABANDONED FEEDLOTS

The data collected to date indicate that growing alfalfa limited the movement of nitrate below the root zone. Corn also reduced the nitrate movement; however, movement below the root zone of this crop occurred. The alfalfa forage could be used for livestock feed, whereas the nitrate content of the corn forage was too high to be used as a feed unless ensiled or mixed with other feed. The alfalfa yields are much greater than those of corn; therefore, the nitrogen removal from the soil is greater. No salt damage was evident on the plots planted directly in the feedlot, and therefore, the removal of the top 15 cm (5.9 in.) of feedlot soil may not be necessary).

## AIRBORNE POLLUTANTS

Feedlots and even pastured cattle can contribute distillable N to the atmosphere. The majority of the distillable N was $NH_3$; however, an appreciable portion of the volatilized basic N-compounds was aliphatic amines.

The importance of atmospheric $NH_3$ as an agent for the transport and redistribution of N both within and among ecosystems has been vastly underestimated. Cattle feedlots are apparently a major source of $NH_3$ in the atmosphere. Calculations based on the data collected indicate that annual $NH_3$ absorption by plant canopies growing in air containing $NH_3$ at normal atmospheric concentrations could be about 20 kg/ha. (17.8 lb/acre). This rate of $NH_3$ supply is large enough to contribute significantly to the N budget of a growing plant community and could exert a prodigious influence on the long-term behavior of an ecosystem. Near cattle feedlots where the atmosphere is enriched with feedlot volatiles, foliar $NH_3$ absorption is probably even higher. Our data suggest an important role for green vegetation in the decontamination of the earth's atmosphere.

A significant amount of the $NH_3$ volatilized from the surface of cattle feedlots is absorbed by soil and water surfaces in the vicinity of the feedlots. The data invalidate the concept that only runoff and deep percolation from cattle feedlots require control to prevent N enrichment of the surrounding environment. Although control of runoff into streams to prevent pollution by sediment, phosphorus, and organic wastes justifies adequate and often expensive design of feedlot installations, N pollution can still occur.

There is a potential for aliphatic amines volatilized from feedlots to affect water ecosystems. Chemical theory and observations suggest that gaseous aliphatic amines can accumulate in water exposed to low atmospheric concentrations of these compounds. Microorganisms that degrade aliphatic amines were found in lake water. Microbial activity in water bodies which absorb amines is probably sufficient to inhibit amine accumulation during warm temperature seasons. Wintertime accumulation of amines may occur due to the lack of microbial activity in cold water.

There is the possibility that individual aliphatic amines may affect the usual spring burst of algal growth. Aliphatic amines are toxic to *Chlorella ellipsoidea* at individual amine concentrations from 1.2 ppm for methyl amine to 143 ppm for *iso*-propyl amine. The amines appear to stimulate algal growth at very low concentrations. The alga could not utilize the amines as a source of N, but amines do accelerate ammonium assimilation by the organism. Algal photosynthesis is hindered while respiration is enhanced by methyl amine. The amines may be affecting *C. ellipsoidea* metabolism by accelerating ammonium assimilation which would lead to the observed accelerated consumption of oxygen both in the light and in the dark by the increased tricarboxylic acid cycle consumption of the oxygen and would account for the lack of decrease in ATP concentration when methyl amine was added.

Carbonyl sulfide and $H_2S$ are produced from anerobically decomposing animal wastes. Also, observations of cattle pens and conversations with feedlot operators indicate substantial odor reduction when sawdust is generously used as bedding. In a related laboratory study, adding $KNO_3$ to incubating manure eliminated foul odors. Thus, promotion of aerobic processes in feedlot management can reduce odor problems. The simplest technique for promoting aerobic conditions is to keep the feedlot well drained.

# SECTION IV

# RECOMMENDATIONS

## COMPOSITION AND AMOUNT OF RUNOFF INCLUDING RELATION TO CLIMATIC VARIABLES, SLOPE, STOCKING DENSITY, SITE, SITE MODIFICATION

Pollution control of runoff transport of materials from beef cattle feedlots can be accomplished best by (1) control of the degree and length of slope factor utilizing diversions and terraces, (2) use of debris basins or solids traps to immediately separate readily settleable solids from the effluent to eliminate problems of combined storage of the solids and effluent, and (3) disposal of the solids and the effluent on cropland after diluting the effluent, if necessary, to reduce salt concentration.

### Weather Factors in Design

It is recommended that the chronic wet periods or periods of continuing wet weather that may be expected over a 10-year period be considered in designing capacities for feedlot runoff-control systems.

### Degree and Length of Slope

In the design of terraces and basins or catchments for sloping beef cattle feedlots, the degree and length of slope factor should not be more than three times that normally recommended for cropland in the eastern Great Plains and Corn Belt. Long slope lengths increase solids transport by overland flow and delay drainage.

Terraces and mounds should be employed in beef feedlots to restrict the length of slope, to improve drainage, and to provide for animal comfort. Terraces should not be encumbered by pen fences; this will permit maintenance and smoothing operations in conjunction with the removal or mounding of wastes in the feedlot.

### Debris Basins

Debris basins in conjunction with feedlot terraces drain better if constructed in elliptical rather than rectangular shape. Multiple riser inlets in a basin should not be spaced further than 40 m (43.8 yd) apart. Planned solids accumulation in a basin should not exceed 20 cm (7.9 in.) before removal. Greater depths require longer times to dry adequately for removal and ultimately result in poor drainage of the basin and odor problems. In most basins, under eastern Nebraska conditions, two removals per year will generally be adequate. Due to variations in storm intensities and amounts and the effects of snow and snowmelts, a fixed removal schedule cannot be recommended. Experience in eastern Nebraska has shown that required solids removal may vary from 1 to 3 times per year.

Debris basins located within feedlots should not have side slopes exceeding 1:4, and 1:5 is preferable. Steep slopes, particularly in deep basins, are subject to increased soil movement, which is further accelerated by cattle traffic. Steep basin side slopes make removal of solids more difficult and during wet weather can become hazards for sick or weakened animals.

Debris basins located outside of feedlots should also be designed to permit easy removal of solids. Again, the planned depth of solids accumulation should not exceed the 20-cm (7.9-in.) depth unless removal can be done with a tracklaying tractor. Although outside debris basins eliminate some problems of drainage and solids accumulation associated with basins within the feedlot, they introduce additional areas requiring maintenance and weed control. Under some conditions, flies can breed in the solids collected in outside basins. This problem has not been observed with basins within the feedlot. Crushing of larvae by animal traffic is a means of insect control.

Because of the nature of the runoff from eastern Colorado feedlots, debris basin designs were not evaluated. Runoff from these lots is very viscous and similar in physical characteristics to the material retained in the debris basins in eastern Nebraska. Thus, detention facilities in eastern Colorado should be designed with primary consideration for operation as slurry storage and subsequent removal of the effluent.

Debris basins within the feedlot provide three advantages: (1) animal traffic hastens the drying of nominal depths of collected solids; (2) basins provide protection for animals from wind through much of the winter; and (3) should snow removal be required in the feedlot, basins are a logical disposal area.

### Solids Removal

Operators must remember that a 10-cm (3.9-in.) depth of dry organic material in a debris basin or other area within a feedlot provides the only ingredient required other than water from rain or snow to create a slurry 20 cm (7.9 in.) or more in depth. Removal of accumulated organic materials can be accomplished most easily when these materials are dry and in nominal depths.

Where debris basins are not used, solids traps utilizing hardware-cloth screens (9.5 cm mesh) (3.7 in.) in broad, level channels are recommended for separation of readily settleable solids from the runoff. These solids must be separated from runoff prior to storage of the runoff effluent in a holding pond to reduce production of odors and eliminate deep accumulations of wet solids which cannot be removed readily.

### Holding Ponds

Sealing of the soil surface after construction of a holding pond should not be necessary, even on a permeable soil, unless a domestic water well is located in the immediate vicinity. The organic solids in the runoff effluent will soon effectively seal the soil surface to continued infiltration.

Holding ponds should not be excessively large. Designs should be for 120 cm (47.2 in.) or greater depths for storage. Reducing the area will reduce weed problems and potential salt accumulations.

To reduce odor production, runoff collected during cold or cool weather should be removed from the holding pond prior to continuing warm weather. Holding ponds should be exposed to maximum wind movement. Feedlots should be constructed downwind from residences and not in the prevailing wind direction from nearby residences and water bodies.

### Drainage Systems

Underground plastic drainlines provide a highly satisfactory means of discharging runoff effluent from the feedlot or a debris basin. Flow may be by gravity or by low pressure from a pump. Such systems eliminate the problems of settled solids, weed growth, and restrictions of traffic imposed by open channels.

### Corrosion-Resistant Materials

Accelerated erosion due to contact with solids collected from feedlot runoff or the runoff effluent has not been observed. Portable aluminum irrigation pipe and brass sprinkler heads are satisfactory for distribution of effluent. Galvanized (zinc-coated) hardware cloth and penta-treated wood can be expected to last for 5 years or more in intermittent contact with solids collected from runoff. Pumps with cast-iron or bronze impellers are satisfactory for pumping the effluent.

## DISPOSAL OF RUNOFF

### Land Disposal of Runoff

Land application of effluent from feedlot runoff is the most feasible means of disposal in eastern Nebraska. Runoff is not a dependable supply for irrigation, and applications of runoff effluent beyond the water requirements of crops will be necessary for disposal in wet seasons. Where irrigation is not practiced, regularly produced field crops or grass should be grown on the disposal area.

In the subhumid and semiarid areas, crops with critical-period water requirements may fail in dry seasons. Disposal areas twice the size of the contributing area are adequate in the eastern Great Plains and in the Corn Belt.

The high concentration of solids and salts in runoff from eastern Colorado precludes its direct application to cropland, unless diluted with irrigation water to reduce electrical conductivity to a satisfactory level.

## SOIL PROPERTIES UNDER FEEDLOTS

If feedlots are kept stocked continuously, there is little likelihood that nitrate or other soluble pollutants will percolate through the soil profile to the water table, even when it is at a very shallow depth.

Cleaning operations are necessary to remove solid wastes, but scraping operations should not destroy the interface layer under the manure layer.

New feedlots should be stocked to capacity immediately and kept at full capacity at least the first 1½ years.

## INVESTIGATIONS ON METHODS OF EXTRACTION OF NITRATE FROM THE SOIL PROFILES OF ABANDONED FEEDLOTS

Alfalfa can be established in an abandoned feedlot to prevent or minimize the downward movement of nitrate-nitrogen. The forage produced is safe for use for feed.

## AIRBORNE POLLUTANTS

Feedlots contribute N to atmosphere principally as $NH_3$ but including amines and other unidentified substances. Ammonia can be scavenged or absorbed by plants, soils, and water bodies. Plants in the vicinity of feedlots may derive a considerable portion of their nitrogen requirement from volatilized ammonia. Whereas, water bodies may become eutrophic or well nourished to their N needs. Since the prevailing wind is from west to east, it is recommended that, where possible, feedlots be built windward or east of existing water bodies. The toxicity of aliphatic amines to organisms that reside in the vicinity of cattle feedlots does not appear to be an immediately acute problem. The potential does exist for direct ill effects on organisms in an area to occur as the cattle population density increases. The synthesis of aliphatic amines, carbonyl sulfide, and $H_2S$ is engendered by anaerobic conditions in the feedlot manure pack. For feedlot odor control, it is important that the feedlot be kept as well drained as possible.

Management practices, such as using sawdust mulches, which keep the manure pack as aerobic as possible should keep the production of aliphatic amine, carbonyl sulfide, and $H_2S$ to a minimum.

## SECTION V

## DESCRIPTIONS OF FIELD SITES, SPECIAL FACILITIES, AND METHODS

### NEBRASKA SITES

### Level Feedlot, Central City, Nebraska

A level feedlot has been under study in the Platte River valley on the T. C. Reeves' farm, west of Central City in Merrick County, about 165 km (102 miles) west of Lincoln. The soil is a silt loam underlain with sand and gravel and a water table that fluctuates between 60 and 305 cm (23.6 and 120 in.). The water table is lowered during irrigation and recovers rapidly following heavy rainfall. Groundwater levels, movement, and quality were measured (2, 3, 4).

Caissons were installed to a depth of 183 cm (72 in.) beneath the feedlot surface so pollutants in the soil water and gases in the soil profile could be studied. The caissons contained portholes so soil-solution and soil-gas samplers could be placed at increments in the soil profile. In this manner, *in situ* samples could be obtained from the same point over long time periods. Soil-solution samples were used to assess pollutants moving through the soil profile and soil-gas samples were used to determine the reduction status of the soil profile. A caisson prior to installation is shown in Figure 1 and an installed caisson with samplers in place is shown in Figure 2. Caisson design, installation, and sampling equipment are described in detail by Elliott, McCalla, Swanson, and Viets (5).

Manure accumulated on this lot without appreciable removal for 15 years. The manure pack was 30 to 40 cm (11.8 to 15.7 in.) deep when mounds were first built in August 1969. In late 1971, a moderate slope was built into drainways between the three mounds in the lot, with drainage to three sumps connected by underground lines. Runoff collects in the central sump and is pumped underground to a holding pond lined with polyethylene. This system has functioned well since installation. Lack of drainage during wet weather has presented severe problems on this lot in the past (6).

Traps containing dilute sulfuric acid were used on this site to compare the $NH_3$ contents of the air in the immediate vicinity of the feedlot with air in surrounding cropland and to identify odor compounds (7).

### Sloping Feedlot on Deep Loess Hill, Gretna, Nebraska

A sloping feedlot with a southern exposure on a typical, deep loess hill is being studied on the Howard Krambeck farm, north of Gretna in

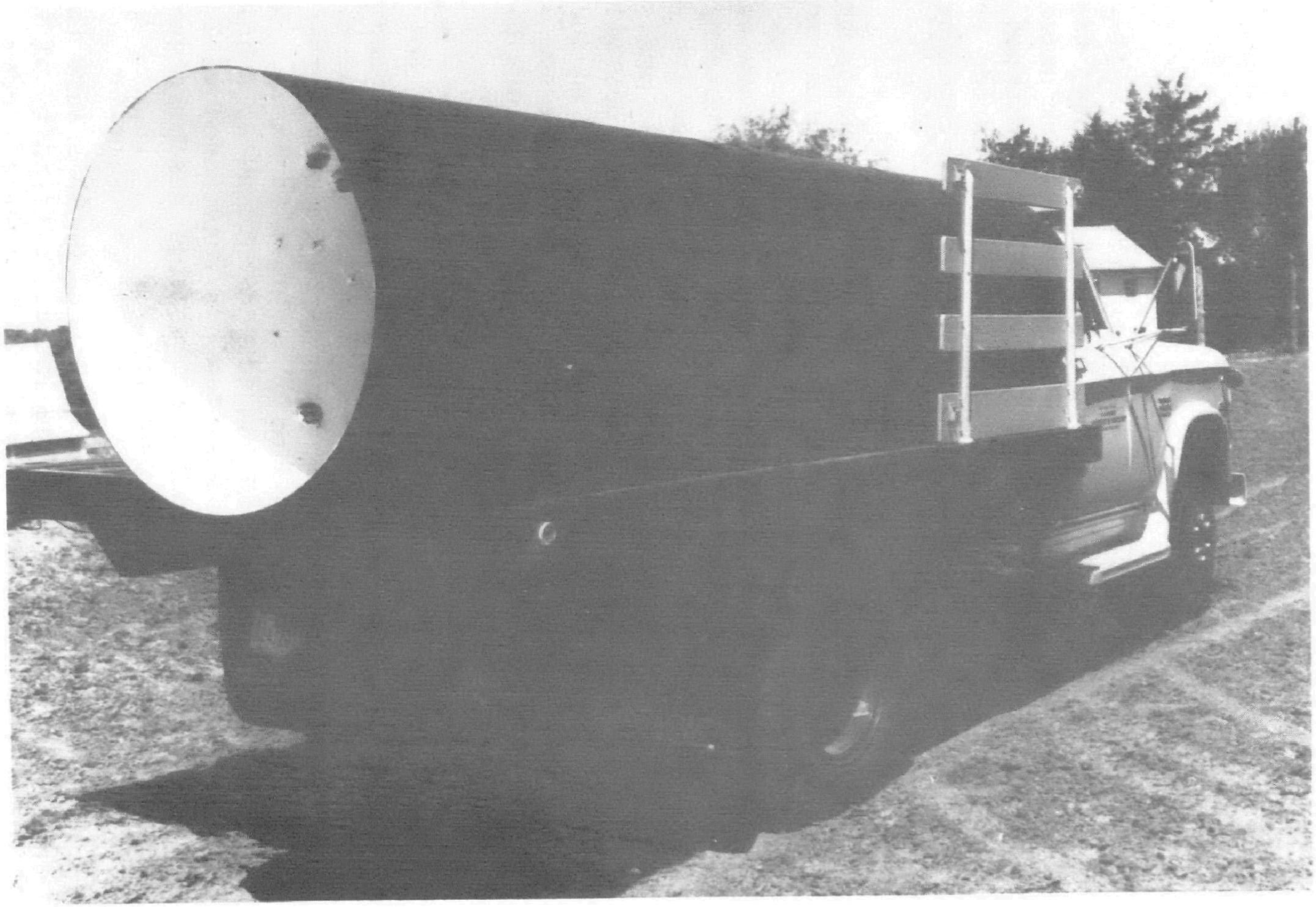

Figure 1. Caisson before installation in the soil.

Figure 2. Installed suction cup assemblies and gas samplers.

western Sarpy County. Runoff from rain and snow and the movement of organic wastes and soil were measured. Climatic factors, in addition to rainfall, were measured to evaluate their effects on the amount of runoff and solids transported. Solar radiation, evaporation, wind movement and direction, soil water under the feedlot and adjacent grassland, as well as groundwater quality and water levels were measured. A trap was installed to collect solids transported in the runoff prior to their reaching the holding pond. A programmed, automated sampler was used to monitor runoff quality (8).

The solids trap consisting of three, hardware-cloth screens set across a 4.3- by 26-m (1.7- to 10.2-in.) channel retained most of the solids before the runoff reached the holding pond. The debris trap was cleaned periodically with a tractor-mounted, front-end loader (9).

### Steep, Sloping Feedlot with a Broad-basin Terrace, Omaha, Nebraska

Broad-basin terraces have proved to be a workable method of feedlot runoff control. A broad-basin terrace was installed on a lot with a 15% easterly slope at Underwood Farms, northwest of Omaha. The runoff plus solids was collected in the basin. Recorders in the basin measured the amount and rate of runoff inflow. The runoff water was pumped from the basin and applied to adjacent cropland. The solids drained and dried sufficiently for removal with a front-end loader. The basin had a capacity of 30 cm (11.8 in.) of runoff and did not have to be emptied frequently (10).

### Sloping Feedlot with Broad-basin Terraces, Springfield, Nebraska

Broad-basin terraces were installed on a feedlot with a southwesterly 7% slope, 183 m (200 yd) long, west of Springfield at the William Cockerill farm. Each terrace retains runoff from an area of a different size. This installation was equipped with runoff-recording equipment, and underground plastic pipe drained the water from the terrace basins to storage in a holding pond from which it was pumped for application on cropland (10). Physical and chemical effects of runoff-effluent applications on the soil and plants from Ladino clover, tall fescue, perennial ryegrass, corn, and forage sorghum plots were studied. Yields and nutrient content of the crops were measured. Three caissons were installed on this site (one on the slope, one in a basin of the feedlot, and one in an adjacent field) to monitor pollutants in the soil water and gases in the soil profile to determine what occurs under a newly established feedlot.

The terrace system on this feedlot was altered in 1973 to provide better cattle access to feedbunks and waterers. Pen fences were moved from the terrace crowns and riser inlets were installed near the center of the debris basins. The outlet from the lower basin was moved from the holding pond and extended to discharge onto a leveled area of cropland. The cropland area was surrounded by a low earthern dike to prevent runoff.

## Feedlot Located on Streambank, Colfax County, Nebraska

This site on the William Krula farm was located partially on the floodplain of East Fork of Maple Creek, which has a long history of serious flooding. The installation included a dike, 3 m (3.3 yd) high, built along the lower side of the feedlot. The top of the dike was 60 cm (23.6 in.) above the record flood stage and kept feedlot runoff and wastes out of Maple Creek during any storm. The basin in the feedlot was about 150 m (164 yd) long and 15 m (16.4 yd) wide at the bottom, with 4:1 slopes coming into it. The basin held 10 cm (3.9 in.) of runoff plus 1.3 cm (0.5 in.) of solids from the 2.63 ha. (6.5 acres) drained in this portion of the lot. This is adequate capacity for any 24-hour storm expected in a 10-year period (11).

Runoff from the feedlot collected in the basin and drained through three riser inlets, then through a 15-cm (5.9 in.) plastic underground line into a sump equipped with a 1/2 hp electric sump pump. The runoff was pumped through a 7.6-cm (3-in.) plastic line to a holding pond near the lot on a higher elevation. The runoff collected in the holding pond was spread as irrigation water on an irrigated field near the holding pond. This water spreading was done during dry weather, utilizing a large, plastic siphon connected to gated irrigation pipe.

This feedlot also included a broad-basin terrace with an underground pipe discharge to the holding pond and has capacity for about 1,000 cattle.

## Feedlot with a Defined Drainage Channel, Stanton County, Nebraska

This installation included a series of lots or pens on the Paul Wiemann farm traversed by continuing drainway. Runoff from outside the feedlot site was diverted by means of a diversion terrace. Wooden frames, covered with hardware-cloth screens, served as debris traps and are located at selected locations in the drainway through the lots. Upon leaving the lots, the drainway entered a nearly level, 12- by 120-m (13 by 131 in.) debris trap, similarly equipped with such screens. The runoff deposted most of its solids before discharging into a drop inlet to a holding pond for later application to an adjacent field. This site also included a lot with a broad-basin terrace with an underground discharged to the holding pond. The total capacity was in excess of 1,000 cattle.

### Beef Cattle Feeding Complex, University of Nebraska Field Laboratory, Mead, Nebraska

Specially constructed pairs of pens with 3%, 6%, and 9% slopes have been studied at the University of Nebraska Field Laboratory. Detention basins were constructed at the lower end of each lot to retain runoff. Each basin was equipped with a water-level recorder to record the duration, rate, and quantity of runoff. Two stocking rates were studied simultaneously in the pairs of pens to learn the effects of animal density and surface slope on characteristics of runoff, solid wastes, and nitrate movement on unpaved, beef feedlots.

Two systems of runoff control also have been studied at this site to determine the pollutants and solids transported from the feedlot pens. One system collected the runoff and solids from a runoff event; the effluent was drained off after the solids settled. The second system utilized rock-filled dams in a nearly level channel to retain the solids and permit drainage of the runoff effluent to a holding pond.

### Abandoned Feedlot Study, Gretna, Nebraska

To study the pollution potential of abandoned feedlots, an active feedlot was selected and a portion of it abandoned. The site, on the Rodney Weeth farm, was on an upland slope on typical, deep loess soil, just south of Gretna, in western Sarpy County. The area is being cropped with alfalfa and corn to remove nitrogen from the soil profile and to attempt prevention of downward movement of nitrate.

### Core Drilling Study of Nebraska Beef Cattle Feedlots

Fifteen feedlot sites in four eastern Nebraska counties were selected for this study. The sites were located in Cuming, Douglas, Sarpy, and Polk counties, where large numbers of cattle are fed in confined feedlots. One or more sites were used to evaluate each of the effects of feedlot age, management, soil texture, and topography on the nutrient status of the soil profile and groundwater. Six feedlots were located in the Elkhorn River Basin, five in the Platte River Basin, and four in the Papio Creek Basin. Two of the Platte River Basin sites were on the floodplain. One hundred and three cores were taken from feedlots, 22 from cropland, and 4 from cropland-cattle-use areas.

Management considerations included stocking rate, manure-scraping, and mounding practices. Age of feedlots sampled ranged from a few weeks to more than 50 years, with the soil textures ranging from clay to coarse sand. Cropland and grassland areas were cored adjacent to feedlots for comparisons.

Soil samples were taken with a mobile, truck-mounted, coring rig. On most core locations, 5.1-cm (2-in.) diameter, 122-cm (48-in.) long cores were taken through the profile, using hydraulic pressure. In dense and sandy soils, a driving hammer and a 3.5-cm (1 3/8-in.) split-tube sampler were used. Each core was divided into 30.5-cm (12-in.) sections. Alternate sections were placed in a plastic bag, sealed, and frozen immediately with dry ice. These samples remained frozen until chemical analyses were performed. The other sections of the core were placed in a bag and retained for physical determinations. Percent moisture by weight (Pw) was determined on each sample. Soil texture was estimated by feel at the sample site; where there was a sharp textural change, samples were taken from above and below the transition. Random comparisons were made of the texture estimates made in the field with those obtained by the standard hydrometer method.

Oxidation reduction potential (Eh) measurements were taken immediately after cores were removed from the sampling tube. A platinum and reference electrode was pushed into the sample, and the reading taken 60 seconds later was corrected to the standard hydrogen electrode.

If groundwater was reached, water samples were obtained. A small, hand-vacuum pump was used whenever possible; however, on deeper samples a tube sampler 60 cm (23.6 in.) long with check valve was used. Some water samples were obtained by pouring off the water trapped in the sampler above the soil core.

Specific profiles were selected from which samples were chosen to characterize the bulk density and the percent water at 1/10-, 1/3-, and 15-bar suctions by standard procedures. The clod method was used to determine bulk density.

## COLORADO SITES

### Level Feedlot (Anderson) and Sloping feedlot (Ashlind), Ft. Collins, Colorado

Two commercial feedlot sites near Fort Collins were selected for hydrologic evaluation. The flat site (Anderson) is on very permeable soil immediately adjacent to the Cache la Poudre River, about 5 km (3 miles) east of Ft. Collins, and was selected for its potential for groundwater pollution. The second (Ashlind) site, about 7.5 km (4.5 miles) northeast of Ft. Collins, is constructed on a deep, fine-textured soil with a uniform slope of 6% and represents a typical feedlot for the area having potential for surface water pollution.

The flat feedlot is 0.2 ha. (.5 acre) in size and is normally stocked with 70 head of cattle. A climatic station, including standard and recording rain gages, anemometer, hygrothermograph, standard class A evaporation pan, and maximum and minimum thermometers, was installed near this feedlot. Three vacuum lysimeters (12) (see Figure 3) were

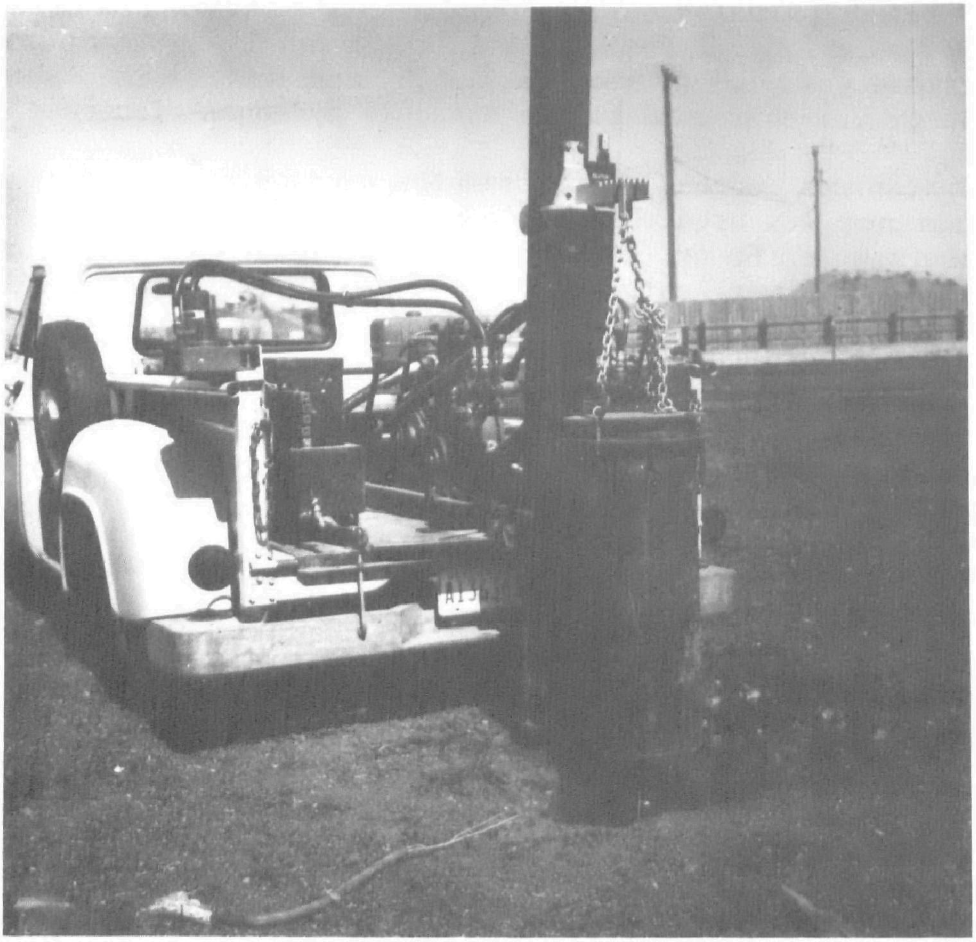

Figure 3. Vacuum lysimeter ready to be lowered into position near center of flat (Anderson) feedlot.

installed to determine the quantity and quality of percolate moving through the soil profile. One lysimeter was installed immediately behind the concrete feedbunk apron where the soil was continually moist from animal excretion. A second lysimeter was placed in the normally dry center of the lot, with the third at an intermediate position. The cobble subsoil precluded installation of access tubes for neutron soil water measurements.

During the years 1969 and 1970, the animal drinking water was measured directly with a domestic water meter, but then a change in water source and attendant trash problems rendered the meter inoperative. Subsequent drinking water consumption was calculated from the number of animals in the lot and earlier measured consumption for a comparable time of year.

The sloping (Ashlind) lot covers 0.4 ha. (1 acre) and is normally stocked with about 225 head of cattle. This site was equipped with three vacuum lysimeters as in the flat lot. After 2 years of operation, no detectable movement of percolate had been measured, and further operation of the lysimeters was discontinued. Six tubes for neutron measurement of soil water were located randomly through the lot to further delineate changes in soil water content. A diversion dike constructed near the lower end of the lot (Figure 4) diverted surface runoff through a recorder-equipped flume for quantitative measurement. A pump sampler was provided to collect periodic samples during each runoff event. However, as apparent from Figure 4, the surface water leaving the feedlot during a runoff event was very heavily sediment laden. This heavy sediment concentration made it impossible to collect samples by pumping; therefore, only periodic grab samples were available for chemical analysis.

Because of the proximity of the two sites (5.8 km or 3.6 miles), only the standard and recording rain gages were installed for climatological measurements at the Ashlind site.

### Caissons at Ashlind Feeders, Inc.

A nearly level feedlot pen located downslope from the vacuum lysimeter installation at Ashlind Feeders, Inc., along with a nearby alfalfa field, was selected in December, 1970, for installation of three steel-cased caissons similar to those already described. One caisson was installed near the feedbunk, the lowest elevation in the pen, and the other near the center at the highest elevation. The third caisson in the nearby alfalfa field served as cropped field comparison. The caissons were instrumented in 1971 to collect data on soil temperatures, soil water tension, soil gases, and soil solutions. All three caissons were placed deep enough to reach the water table or well within the capillary fringe of the water table, 3.7 to 4.3 meters (12 to 14.1 ft).

Figure 4. Sloping (Ashlind) feedlot immediately following 6.6 cm of rainfall, June 1970. Note diversion dike in left center of photo and extremely viscous liquid draining toward flume in immediate foreground.

## Experimental Percolation Feedlot, Colorado State University, Fort Collins

Observations of the Ashlind and Anderson feedlots led to the development in late 1971 of plans for a major research facility for evaluating effects of feedlot management on percolation of pollutants. It was hypothesized that manure pack management could reduce the quantity and concentration of pollutants in percolating soil water. To test the hypothesis, a research feedlot was constructed at the Colorado State University Animal Research Center, 7.5 km (4.7 miles) southeast of Ft. Collins. The research feedlot, with 30-head capacity, is 15.2 by 22.9 meters (16.6 yd by 25 yd) in area. Two underground tunnels were constructed, one under the feeding apron, the second near the center of the lot, to provide access to the soil profile beneath the feedlot. Figure 5 illustrates the tunnel under the feeding apron during construction.

Eight artificial soil profiles have been constructed downslope from each of the two tunnels. Each of these profiles was placed in a pit, 1.2 m by 2.4 m by 1.8 m deep (3.9 ft by 7.9 ft by 5.9 ft), excavated adjacent to the tunnels. These pits were lined with a continuous sheet of butyl rubber to assure capture of all percolating water. Each pit is provided with gravity drains, which allow maintenance of the water table at any depth to 183 cm (72.1 in.) below the soil surface. Porous ceramic drains are also provided to allow removal of percolate at sub-atmospheric pressure, thereby simulating a water table depth down to 7.6 m (24.9 ft).

Four soil profiles replicated four times are shown in Figure 6. The plots upslope from Unit B have not been installed although access holes have been provided through the tunnel walls to allow future installation of these additional plots. The uniform sand profile will be sufficiently aerated to maintain aerobic conditions throughout. The clay loam will be irrigated if necessary to maintain an anaerobic profile. The clay/sand profile is intended to maintain the upper layer anaerobic and the deeper layer aerobic. The sand/clay profile is intended to provide nitrification in the upper aerobic layer with subsequent denitrification as water moves into the anaerobic zone beneath.

Each of these test plots is provided with either gravity or vacuum drainage to provide the degree of aeration mentioned above. Tensiometers throughout the profile will be used to indicate soil water status (thereby inferring degree of aeration). Gas and water samples collected at various depths will be analyzed to determine the chemical changes as the water moves through the profile.

Figure 5. Access tunnel, experimental feedlot, prior to backfill and completion of feeding apron.

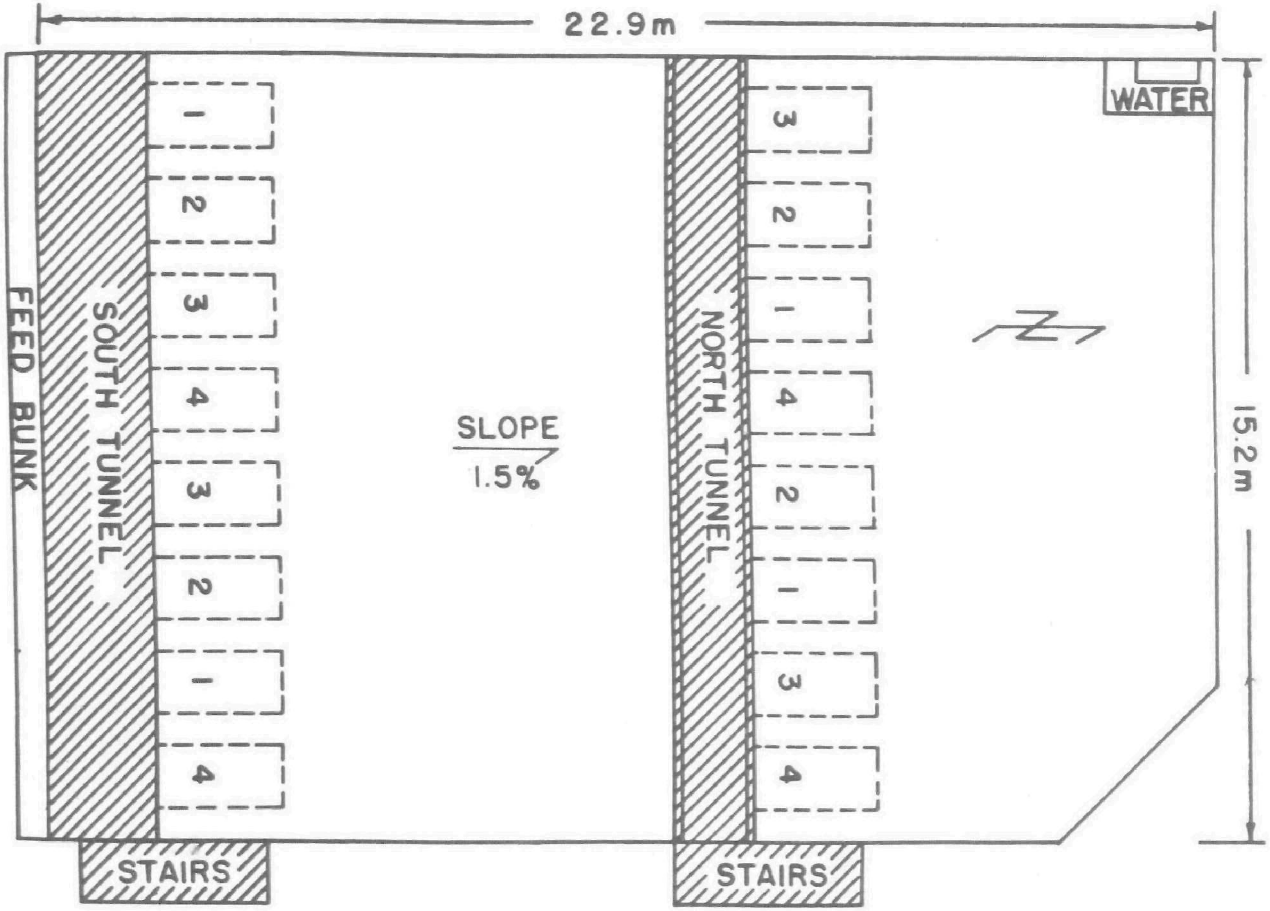

Figure 6. Design of experimental feedlot and arrangement of soil fill (1--clay loam, 2--sand, 3--clay loam over sand, and 4--sand over clay loam) in pits.

# SECTION VI

# COMPOSITION AND AMOUNT OF RUNOFF INCLUDING RELATION TO CLIMATIC VARIABLES, SLOPE, STOCKING DENSITY, SITE, SITE MODIFICATION

## NEBRASKA

### Amount of Runoff

The feedlot at Gretna has a single pen isolated for runoff measurement. This pen, approximately 37 m (40.5 yd) wide with a 91-m (100 yd) slope length and a 6% slope, has a southern exposure. From July, 1968, through December, 1972, precipitation totaled 314 cm (123.7 in.) and occurred on 323 days. There were 89 runoff events and 104 cm (113.8 in.) of runoff (Table 1). It is estimated that about 23 cm (9.1 in.) of runoff can be expected annually from a sloping feedlot with 71 cm (28 in.) of average annual precipitation (13).

A programmed sampler, which passes a slotted dipper through the runoff discharge, is used at this site. Discrete samples of the runoff and its bedload are obtained over 5-minute periods. The sampler is programmed to select 14 samples at preselected times during runoff. This permits both qualitative and quantitative evaluation of the runoff with elapsed time (8).

Table 1. SUMMARY OF RUNOFF EVENTS FROM FEEDLOT PEN, GRETNA, NEBRASKA, 1968-1972

| Year | Days with precipitation | Runoff events | Total precipitation (cm) | Runoff (cm) |
|---|---|---|---|---|
| 1968[a] | 29 | 12 | 49.93 | 22.17 |
| 1969 | 81 | 20 | 56.13 | 14.45 |
| 1970 | 72 | 23 | 61.90 | 14.22 |
| 1971 | 62 | 15 | 67.49 | 23.29 |
| 1972 | 79 | 19 | 76.66 | 29.92 |
| Total | 323 | 89 | 312.11 | 104.06 |

[a] Incomplete record for year; record started with runoff event on July 17.

The data obtained show that runoff may not be expected from rainfall of 1.3 cm (.51 in.) or less unless rainfall has occurred within the previous 72 hours. These data also show that higher rainfall intensities provide both higher runoff rates and increased total runoff. Water storage in the soil and manure mixture on the feedlot surface can be appreciable. However, appreciable water movement into the soil profile of a feedlot with an established manure pack should not be expected during, or from, a rainfall event. Profile moisture measurements show that wetting of the feedlot surface is relatively slow, but significant amounts of rainfall are stored in the organic surface. The stored water is usually lost to evaporation soon after the rain.

Runoff amounts from rains received within one day after other runoff-producing events did not approach rainfall amounts except for relatively high-intensity rains. A regression analysis was made of runoff from 19 individual storms that followed runoff-producing rains. The resulting equation was: runoff = 0.03 + 1.04 x rainfall, with a correlation coefficient of 0.78. This suggests that once moistened, the feedlot surface absorbs water more rapidly.

## Pollutants Transported in Runoff

A selected hydrograph with the runoff-site relationships for runoff from the April 18, 1970, event (Fig. 7) shows that the comparatively high initial $NH_4$-N and $NO_3$-N contents drop rapidly (23 to 9 ppm and 9 to 1 ppm, respectively) during the first hour after runoff starts. This occurred with a continuing rainfall intensity of about 0.5 cm/hr. A similar hydrograph for the following day (Fig. 8) indicates that after a short cessation of rainfall, the $NH_4$-N content of the runoff again will be relatively high (16 ppm) and may be expected to drop (2 ppm) within an hour. On the other hand, the $NO_3$-N content (less than 1 ppm) will not increase with the resumption of runoff. The $NH_4$-N and $NO_3$-N are washed out rapidly from the feedlot surface by the runoff. However, only a short interval without runoff is required for the accumulation of additional $NH_4$-N for subsequent removal.

A similar relationship is shown by $NO_3$-N in the runoff for the September 23, 1970, storm (Fig. 9) except that $NH_4$-N in the runoff fluctuated (27 to 12 ppm) throughout the 5.5-hour sampling period.

The total solids content in runoff that occurred on April 18 and 19, 1970, ranged from 0.40% to 1.52% and from 0.46 % to 1.26%, respectively. The September 23 runoff had a solids content ranging from 0.36% to 0.54%. The higher solids contents observed during the April 18-19 runoff events occurrred in conjunction with periods of higher rainfall intensity, although the intensities ranged only from 0.5 to 0.65 cm/hr (.2 to .26 in/hr). Even very moderate increases in rainfall intensities can be expected to greatly increase the solids

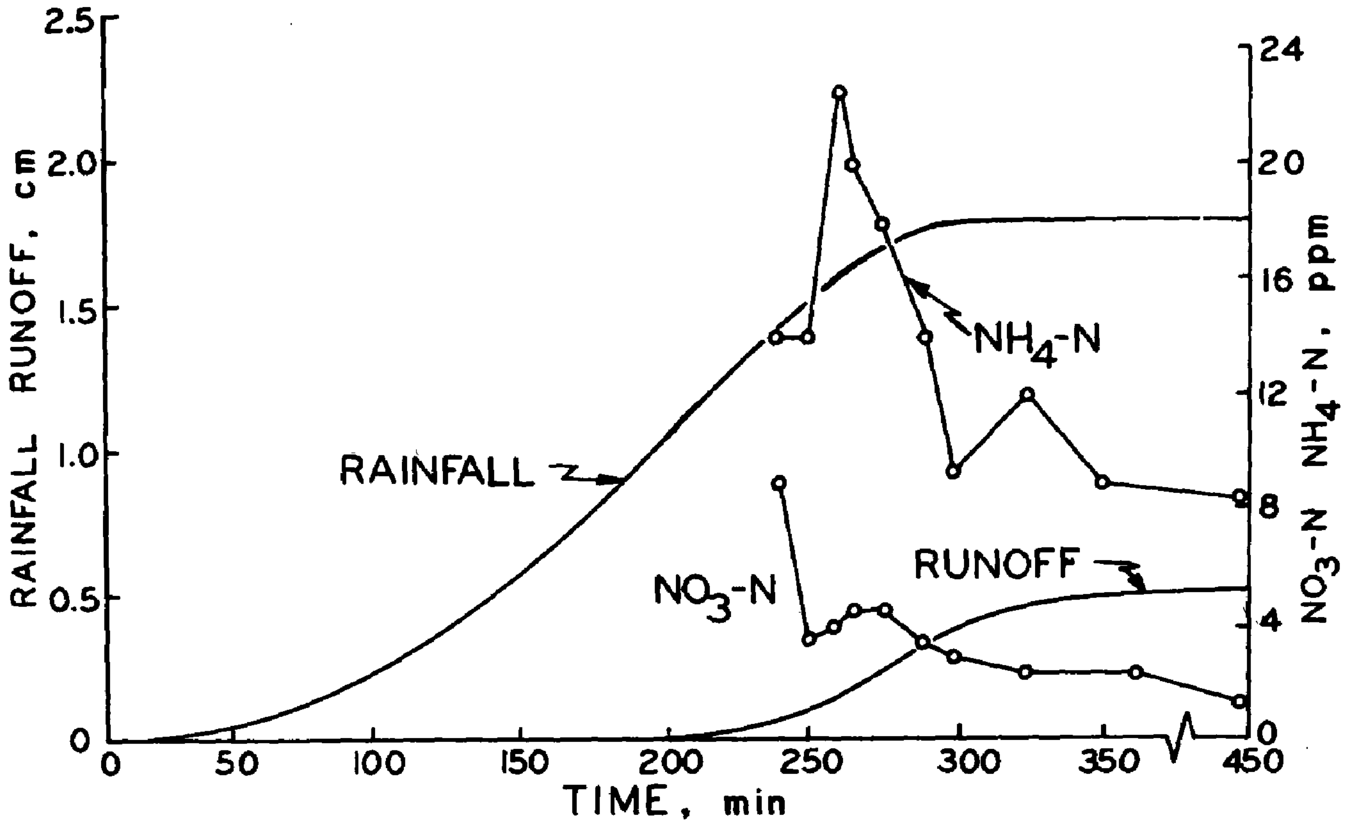

Figure 7. Rainfall, runoff, and $NH_4$-N and $NO_3$-N concentrations in runoff, sloping cattle feedlot, Gretna, Nebraska, April 18, 1970.

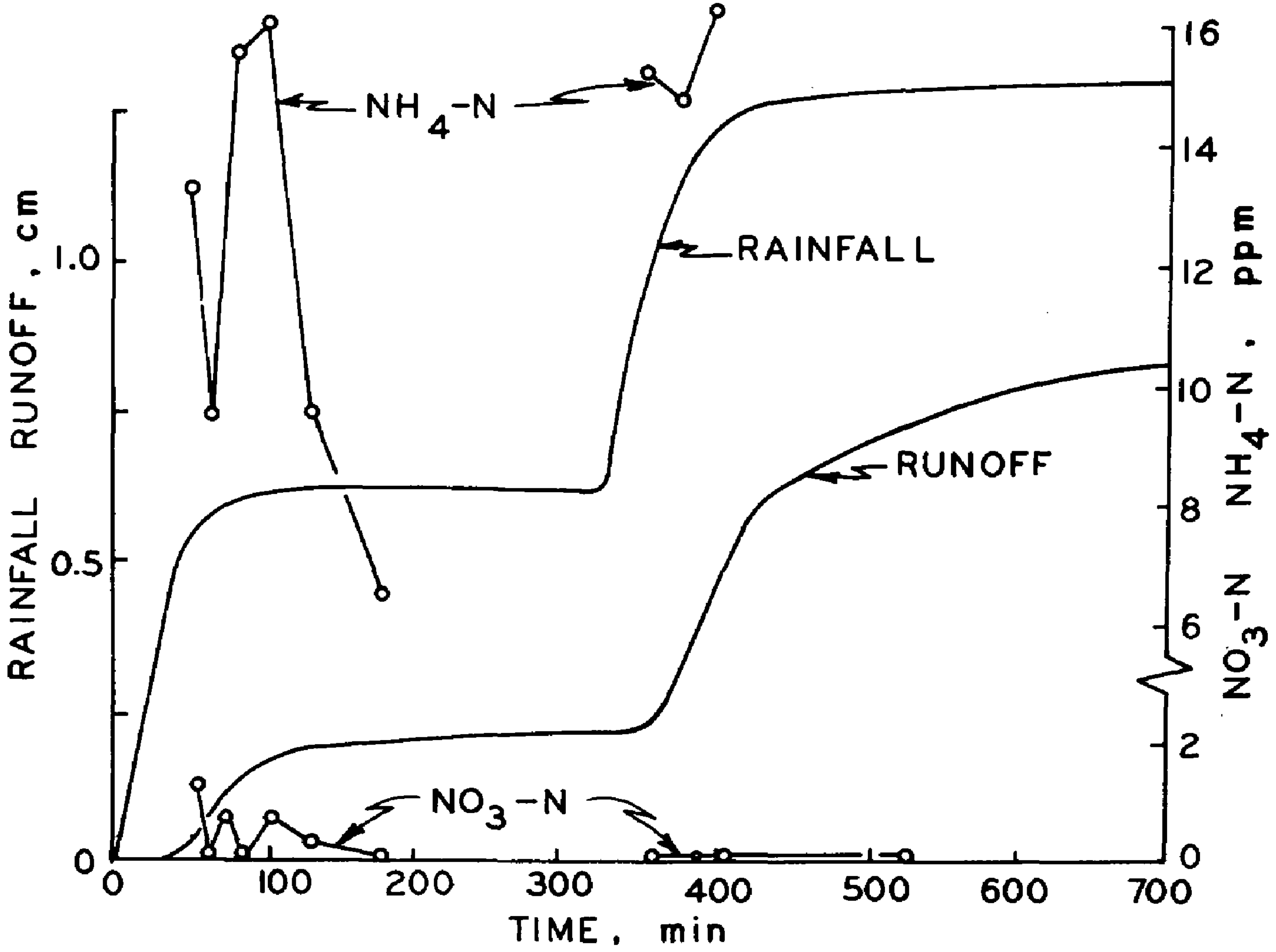

Figure 8. Rainfall, runoff, and $NH_4$-N and $NO_3$-N concentrations in runoff, sloping cattle feedlot, Gretna, Nebraska, April 19, 1970.

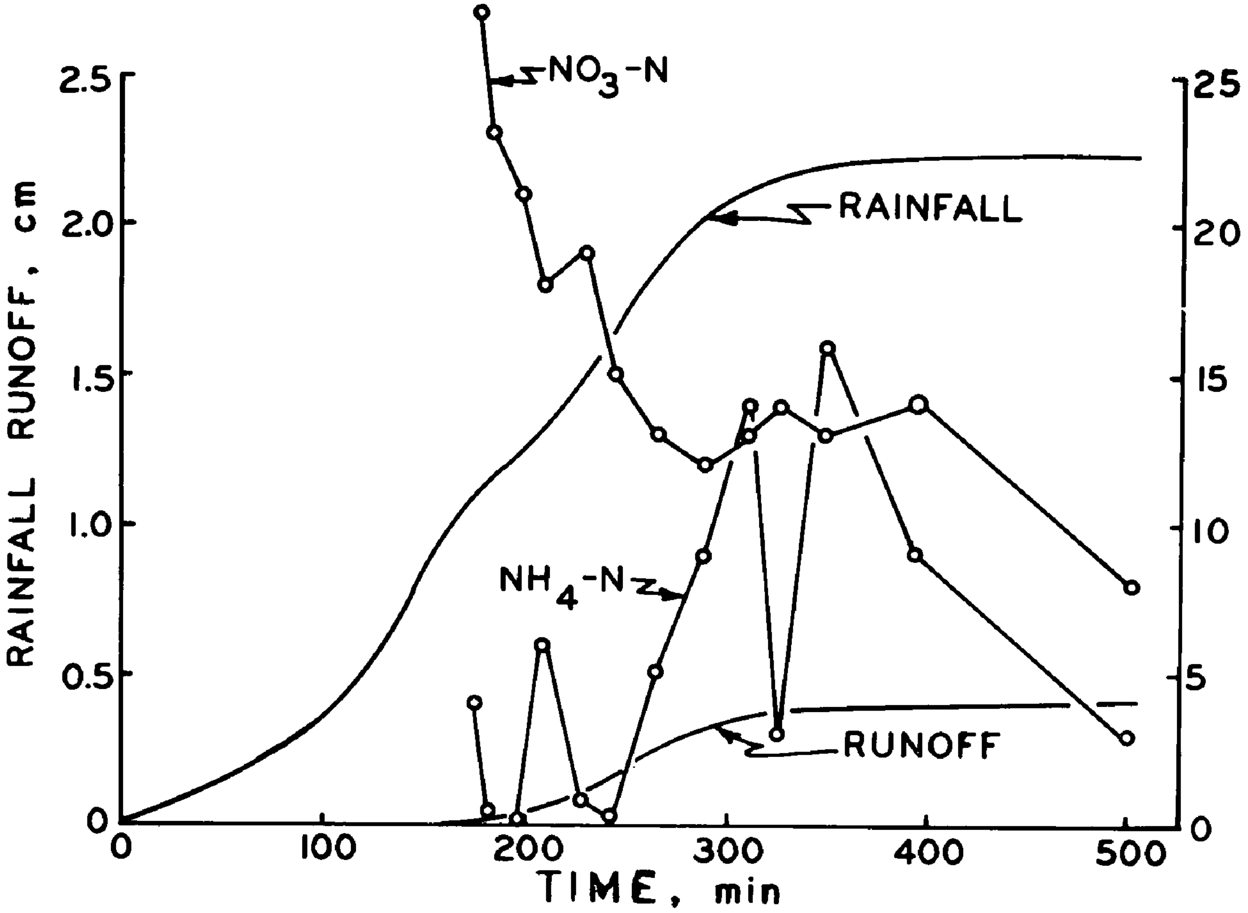

Figure 9. Rainfall, runoff, and $NH_4$-N and $NO_3$-N concentrations in runoff, sloping cattle feedlot, Gretna, Nebraska, September 23, 1970.

transport from a sloping feedlot by a unit depth or volume of water. This effect is significant because a 1% solids content in runoff is equivalent to 10 metric tons of solids in a 10-cm depth over a hectare (4.46 tons/acre).

Based on the data presented, 30.48 cm (12 in.) of feedlot runoff may contain from 27 to 2.5 kg (59.5 to 5.5 lbs) of $NH_4$-N, from 10 to less than 1 kg (22 to 2.2 lbs) of $NO_3$-N, and about 45 kg (99 lbs) of P. From April through October, 1970, a total of 91 runoff samples were analyzed from 10 storms, providing three or more samples per storm. The chemical oxygen demand ranged from 144 to 12,790 ppm. Phosphorus ranged from 0 to 771 ppm and averaged 38.8 ppm. Solids ranged from 0.18% to 2.18% with an average of 0.75%. Volatile solids ranged from 19.6% to 75.0% of the total solids and averaged 36.0%. Assuming that the average solids content of runoff from the feedlot will not exceed 1% for an expected 23 cm (9.1 in.) annual runoff, the annual solids loss can be estimated at 23 metric tons per hectare (10.3 tons/acre).

A solids trap, consisting of a broad, flat channel 4.3 m (4.7 yd) wide and 26 m (28.4 yd) long with three transverse screens, was installed to collect solids from runoff of the feedlot at Gretna. A total of 78 $m^3$ (.76 acre-inches) of solids were retained in the trap from July, 1969, through February, 1971. Bulk densities of these solids ranged from 0.36 to 0.66 $g/cm^3$ (.013 to .024 lb/cubic inch). Rainfall totaling 101.1 cm (39.8 in.) for the 39 runoff events during the 2½ -year period contributed to 39.6 cm (15.6 in) of runoff, which deposited an estimated 38.8 metric tons (42.8 tons) of solids in the trap. Total precipitation for the 2½-year interval was 159 cm (62.6 in.). The trap has an estimated efficiency of 80% for settleable solids. The solids retained by the trap ranged from 22% to 59% organic matter at the time of removal (9).

It also can be estimated further that soil and organic matter equivalent to 2.4 cm on the feedlot was carried in the 101.1 cm of runoff. If a bulk density of 0.50 is assumed, the average solids content of the runoff was 1.2%.

### Solids Transport

Solids transport by runoff was measured also by solids accumulations removed from basins of feedlot terraces at Omaha and Springfield. These values are shown in Table 2. The solids movement on all three sites falls into the expected pattern for slope and slope length (10).

### Runoff and Pollutants

At Mead, as well as at Springfield, Nebraska, about 23 cm (9 in.) of the 71 cm (28 in.) annual precipitation will run off (14). Three to six percent of the material deposited on a feedlot will be transported in the rainfall runoff. The quantity of material removed will be much higher if snowmelt runoff is included.

Table 2. SOLIDS ACCUMULATIONS REMOVED FROM BASINS OF FEEDLOT TERRACES WITH CONTRIBUTING AREAS OF VARYING SLOPE AND SLOPE LENGTHS, OMAHA AND SPRINGFIELD, NEBRASKA, JULY 1971

| Location | Slope, (%) | Slope length, (m) | Basin area ($m^2$) | Solids[a] volume ($m^3$) | Equivalent depth in basin (cm) | Contributing area ($m^2$) | Total lot area ($m^2$) | Equivalent depth in lot (cm) |
|---|---|---|---|---|---|---|---|---|
| Omaha | 15 | 104 | 1,300 | 15,115 | 43 | 5,472 | 6,772 | 8.26 |
| Springfield | | | | | | | | |
| Basin-1 | 5 | 30.5 | 697 | 2,519 | 13.4 | 1,623 | 2,320 | 4.02 |
| Basin-2 | 6 | 45.7 | 1,104 | 2,408 | 8.2 | 4,180 | 5,283 | 1.68 |
| Basin-3 | 7 | 51.8 | 641 | 3,229 | 18.6 | 5,149 | 5,790 | 2.07 |

[a] Total accumulation since construction in July 1969.

The characteristics and chemical composition of runoff from snowmelt and rain are shown in Table 3. The annual quantities of materials removed in runoff from feedlots in rainstorms and during snowmelt runoff are shown in Table 4. The pH ranged from 4.0 to 9.4, and electrical conductivity was as high as 4.9 and 19.8 mmhos/cm in summer and snowmelt runoff, respectively. Percent total solids were lower in the runoff from rainstorms than from snowmelt. When thaws occurred during some winters, a slurry of undecomposed manure flowed from the lot. The snowmelt runoff that contained high solids content occurred only from lots with cattle that we on high-concentrate diets. Total N in the winter runoff was as high as 6,500 ppm. Nitrate-N varied from 0 to 280 ppm in the runoff from rain.

In 1969, an appreciable amount of material was removed in the snowmelt--119 and 26.9 metric ton/ha. (53 and 12 tons/acre) for 9.3 and $18.6^2$/ animal densities, respectively. Approximately half of the material was volatile solids. Significant amounts of P and N also left the feedlot in runoff. The runoff varied from year to year. Two to three times as much material was removed from the 9.3 $m^2$/animal (100 sq ft/animal) lot as from the $18.6^2$/animal (200 sq ft/animal) lot for 1969 and 1970.

Chemical element content of the runoff is shown in Table 5. Potassium and Mg were high.

## COLORADO

### Composition and Amount of Runoff

Since the flat (Anderson) feedlot has no external drainage, surface runoff was not a consideration at that site during this study. At the sloping (Ashlind) site, runoff resulted from only four to seven rainfall events each year. Figure 10 shows the relation between runoff-producing precipitation and the depth of runoff produced. The correlation between rainfall and runoff was highest when the precipitation during a 72-hour period was used for correlation. Accumulation of rainfall over a 72-hour period apparently compensates for the antecedent moisture in the manure pack. It appears that the water-holding capacity of the manure pack is relatively constant, so long as a manure pack is present. Runoff was never observed during a 72-hour storm of less than 1 cm (0.4 inch), and every storm exceeding that amount produced measurable runoff.

The annual precipitation and runoff at the Ashlind site during the study period is summarized in Table 6.

From Table 1, it is apparent that 15.5 percent of the total precipitation left the feedlot as surface runoff. However, as seen in Fig. 10, about 40% of the precipitation from any event exceeding 1 cm

### Table 3. RANGES IN THE CHARACTERISTICS AND CHEMICAL VALUES OF RUNOFF FROM BEEF CATTLE FEEDLOTS, MEAD, NEBRASKA, 1968-1972

| | Snowmelt runoff | | | Rainstorm runoff | | |
|---|---|---|---|---|---|---|
| | Low | High | Mean | Low | High | Mean |
| pH | 4.1 | 9.0 | 6.3 | 4.8 | 9.4 | 7.0 |
| Conductivity (mmhos/cm) | 3.0 | 19.8 | 7.1 | 0.9 | 5.3 | 3.2 |
| Total solids (%) | 0.8 | 21.8 | 7.7 | 0.24 | 3.3 | 1.93 |
| Volatile solids (%) | 0.6 | 14.3 | 3.9 | 0.12 | 1.5 | 0.82 |
| Ash (%) | 0.2 | 9.2 | 3.8 | 0.12 | 2.8 | 1.11 |
| COD (mg/1) | 14,100 | 77,100 | 41,000 | 1,300 | 8,200 | 3,100 |
| P (ppm) | 5 | 917 | 292 | 4 | 5,200 | 300 |
| $NH_4$-N (ppm) | 6.0 | 2,028 | 780 | 2 | 1,425 | 151 |
| $NO_3$-N (ppm) | 0 | 280 | 17.5 | 0 | 217 | 10 |
| Total nitrogen (ppm) | 190 | 6,528 | 2,105 | 11 | 8,593 | 854 |

Table 4. QUANTITY OF MATERIALS REMOVED IN RUNOFF FROM BEEF CATTLE FEEDLOT, MEAD, NEBRASKA, 1969-1972

| | Total year | | Snowmelt | | Rainstorm | |
|---|---|---|---|---|---|---|
| | Jan 1 | Dec 1 | Jan 1 | Apr 4 | Apr 5 | Dec 31 |
| | 9.3 | 18.6 | 9.3 | 18.6 | 9.3 | 18.6 |
| | $m^2$ per animal | | | | | |
| 1969 | | | | | | |
| Precipitation (cm) | 36.10[a] | 36.10 | 8.39 | 8.39 | 27.70 | 27.70 |
| Runoff (cm) | 17.10 | 16.60 | 6.76 | 4.55 | 10.30 | 12.00 |
| Total solids (Mt/ha.) | 134.00 | 42.60 | 119.00 | 28.00 | 15.00 | 14.50 |
| Volatile solids (Mt/ha.) | 69.50 | 21.20 | 62.60 | 14.30 | 6.90 | 6.81 |
| Ash (Mt/ha.) | 64.90 | 21.40 | 56.80 | 13.70 | 8.07 | 7.69 |
| Total N (Mt/ha. | 3.83 | 1.26 | 3.16 | 0.88 | 0.68 | 0.38 |
| 1970 | | | | | | |
| Precipitation (cm) | 36.80 | 36.80 | 2.98 | 2.98 | 33.80 | 33.80 |
| Runoff (cm) | 14.70 | 19.30 | 1.58 | 2.01 | 13.10 | 17.30 |
| Total solids (Mt/ha.) | 56.10 | 38.20 | 2.09 | 1.28 | 54.00 | 37.00 |
| Volatile solids " | 33.20 | 20.50 | 1.55 | 0.88 | 31.60 | 19.60 |
| Ash (Mt/ha.) | 22.90 | 17.70 | 0.47 | 0.41 | 22.40 | 17.30 |
| Total N (Mt/ha.) | 0.21 | 1.44 | 0.21 | 0.74 | 1.80 | 0.70 |
| Total P (Mt/ha.) | 0.30 | 0.23 | 0.01 | 0.12 | 0.27 | 0.14 |
| 1971 | | | | | | |
| Precipitation (cm) | | 42.60 | | | | 42.60 |
| Runoff (cm) | | 24.60 | | | | 24.60 |
| Total solids (Mt/ha.) | | 53.50 | | | | 53.50 |
| Volatile solids (Mt/ha.) | | 19.10 | | | | 19.10 |
| Ash (Mt/ha.) | | 34.40 | | | | 34.40 |
| Total N (Mt/ha.) | | 1.39 | | | | 1.39 |
| Total P (Mt/ha. | | 0.32 | | | | 0.32 |
| 1972 | | | | | | |
| Precipitation (cm) | | 38.30 | | | | 38.30 |
| Runoff (cm) | | 25.30 | | | | 25.30 |
| Total solids (Mt/ha.) | | 64.80 | | | | 64.80 |
| Volatile solids " | | 28.10 | | | | 28.10 |
| Ash (Mt/ha.) | | 36.70 | | | | 36.70 |
| Total N (Mt/ha.) | | 2.18 | | | | 2.18 |
| Total P (Mt/ha.) | | 0.14 | | | | 0.14 |

[a] Precipitation causing a runoff event

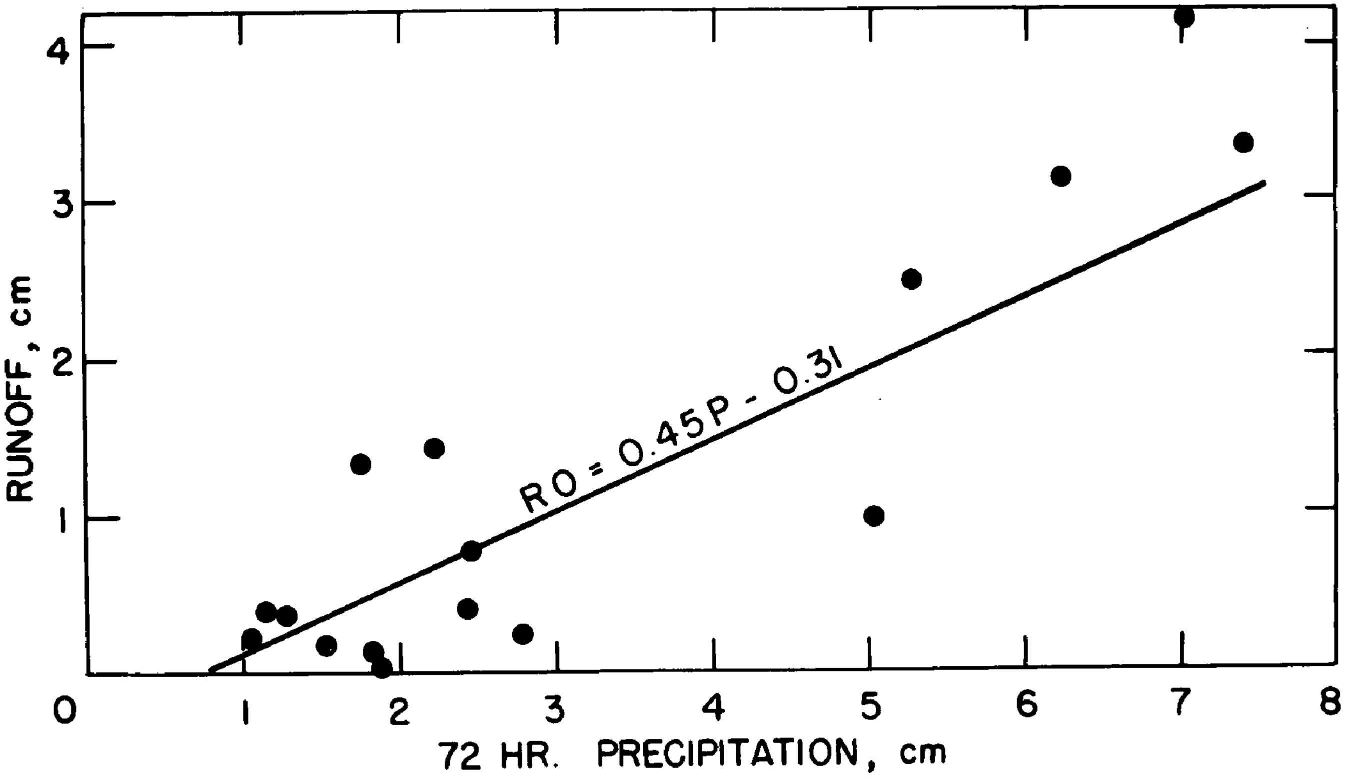

Figure 10. Precipitation-runoff relationship for sloping (Ashlind) feedlot.

Table 5. CHEMICAL ELEMENTS IN RUNOFF FROM BEEF CATTLE FEEDLOTS, MEAD NEBRASKA

| Chemical | Concentration range | | |
|---|---|---|---|
| | Low | High | Mean |
| | ppm | | |
| Na | 90 | 2750 | 840 |
| K | 50 | 8250 | 2519 |
| Ca | 75 | 3460 | 794 |
| Mg | 30 | 2350 | 494 |
| Zn | 1 | 415 | 107 |
| Cu | 0.6 | 28 | 7.6 |
| Fe | 24 | 4170 | 764 |
| Mn | 0.5 | 146 | 26.7 |

Table 6. ANNUAL PRECIPITATION AND RUNOFF - ASHLIND (cm)

| Year | Precipitation | Runoff |
|---|---|---|
| 1970 | 28.09 | 5.66 |
| 1971 | 29.10 | 7.40 |
| 1972 | 27.30 | .09 |

(.39 in.) ran off the surface. Hydrologic studies at both sites were terminated at the end of calendar year 1972.

Table 7 shows the composition of runoff from feedlots near Fort Collins, Colorado. The low annual precipitation and infrequent storms are reflected in the high total solids content of runoff from the sloping Ashlind site (20.4% total solids) compared to that of Mead, Nebraska, in Table 5, which had an average content of 2.0%. In fact, the composition of rainfall runoff at Ft. Collins compares with snowmelt runoff at Mead, Nebraska. Concentration of the chemical species for runoff showed higher values for total, suspended and dissolved solids, $NO_3$, $NH_4$, and total N for material from the sloping lot (facing to the south) than for the level lot in an arid area. In addition, the runoff from Colorado feedlots is higher in salts as is shown by an electrical conductivity of 8 to 12 mmhos/cm as compared to rainfall runoff at Mead, Nebraska, of 0.9 to 4.9 mmhos/cm.

Table 7. CHEMICAL COMPOSITION OF RUNOFF FROM FEEDLOTS NEAR FORT COLLINS, COLORADO

| Measurement unit | Feedlot - Slope | |
|---|---|---|
| | Anderson - 0% | Ashlind - 6% -8% |
| Total solids (g/l) | 17.5 | 204.0 |
| Suspended solids (g/l | 11.8 | 195.6 |
| Dissolved solids (g/l) | 6.6 | 8.4 |
| EC (mmhos/cm at 25°C) | 8.59 | 12.80 |
| pH | 7.19 | 6.75 |
| $NO_3$ (ppm) | 2.96 | 43.4 |
| $NO_2^-$ (ppm) | 0.0 | 0.0 |
| $NH_4^+$ (ppm) | 358.0 | 1,130.0 |
| N (total, ppm) | 1,153.5 | 7,370.0 |
| $PO_4^{3-}$ (ppm) | 114.0 | |
| P (total, ppm) | 92.5 | |
| COD (mg $O_2$/l) | 17,800.0 | |

# SECTION VII

# DISPOSAL OF RUNOFF

## NEBRASKA CONDITIONS

As previously stated, land application for crop utilization of the effluent from feedlot runoff is the most feasible means of disposal under Nebraska conditions and in most of the United States. In addition to the studies discussed, with crops of grass, Ladino clover, corn, and forage sorghum at Springfield, effluent has been applied to bromegrass at Gretna and to cropland used for producing ensilage at Omaha.

At Gretna, established, pastured brome has been subjected to applications of effluent at various times during the season, using both surface flow and sprinkler application. The times of application have been random, dependent upon preceding runoff events. Continued observation has not indicated other than generally beneficial effects from the effluent applications. No evidence of selective grazing (that is, avoidance by the cattle of areas on which the effluent was applied) was noted. Increased forage production and plant vigor were noted.

Effluent applications at the Omaha site have also been dependent upon previous runoff events and have been made by sprinkler and surface application. Forage sorghum stands were not changed by effluent applications before and after planting. Areas receiving applications during the growing season had taller crop growth when approaching maturity.

Feedlot runoff effluent is of direct benefit in supplying the water requirement of crops. However, runoff is not a dependable irrigation water supply. Annual precipitation on the Great Plains tends to be below the mean for 3 years and above for 2 years of five. This means that disposal of runoff can be a problem at times during the two wetter years and be in short supply in the three drier years when water could be used advantageously. Fortunately, runoff can be applied in quantities greater than the crop water requirement without significantly affecting crop quality or yield.

Special corrosion-resistant pumping equipment is not required for the disposal of effluent. Centrifugal pumps, with impellers and casings of both brass and cast iron, have continued to function satisfactorily when used with effluent. Portable, aluminum pipe has been used for 5 years without accelerated deterioration.

The functioning of brass irrigation sprinkler heads has not been impaired by runoff effluent. However, nozzles with small-diameter orifice, 0.5 cm (.197 in) and smaller, have plugged with solids when the pump suction was on the bottom of the impoundment.

## Experience with Holding Ponds

Separation of solids from the runoff prior to storage is desirable. Combined storage of solids and runoff in a lagoon leads to odor production in warm weather. Pumping the solids and runoff from a lagoon is difficult, and drying before removal of the solids is slow and tedious.

The Omaha site utilized a debris basin, providing temporary storage for runoff and longer-term storage for solids. Odor production was not serious, but the basin was essentially isolated from dwellings and work areas. Also, the 15% slope and clay soil of the feedlot surface provided an appreciable quantity of suspended soil materials in the runoff. The soil content of the runoff possibly affected degradation and resulting odor production.

The holding pond at Gretna has not been a serious source of odors. Limited gas production has been observed with warming weather in late spring or early summer. Surprisingly, odors have been limited in both duration and intensity. A volume of 16 $m^3$ (20.9 cu yd) of solids was removed from the holding pond on July 23, 1971. This was the total accumulation of solids in the pond from July 3, 1969, resulting from 31.3 cm (12.3 in.) of runoff produced by 134.0 cm (52.8 in.) of rain over the 2-year period. An additional 62 $m^3$ (81.1 cu yd) of solids from the runoff were collected in the debris basin prior to discharge into the holding pond.

The holding pond at Springfield has been an obvious source of odor with the first periods of continued 32.2°C (90°F) daily temperatures. The settled solids were not removed after construction in 1969 until the holding pond was enlarged in 1973. The relative accumulation of solids was much less than in the holding pond at Gretna. The debris basins at Springfield are even more efficient than the solids trap at Gretna.

Reasons for differences in odor production at the two sites are only speculation. Wind movement on the hillside at Gretna is unrestricted. The Springfield holding pond is on a valley floor, protected by trees and lying immediately adjacent to a building. Odor dissipation by wind movement is definitely restricted at Springfield. Also, tree leaves fall and crop residues are blown into the Springfield holding pond. The pond itself is larger in area, receiving about four times as much runoff. The Gretna holding pond has been emptied periodically and the collected solids have dried. Runoff was stored in the Springfield holding pond to permit maximization of the effluent-utilization studies. Under normal management conditions, the Sprinfield holding pond would have been empty and dry during most of the periods when odor production was a problem.

Site selection for a holding pond might include exposure to wind movement. Sealing of the soil surface after construction of a holding pond should not be necessary, even on a permeable soil, unless a domestic water well is located in the immediate vicinity. The organic solids in the runoff effluent soon effectively seal the soil surface to continued infiltration.

Holding ponds should not be excesively large, areawise. As an example, storage capacity of 15 cm/ha. (1500 $m^3$) per hectare of feedlot contributing area is adequate for most runoff-management systems in eastern Nebraska. The impoundment, however, should be designed for 120 cm or more depth of storage rather than a 60- to 90-cm depth. Reducing the area required will reduce weed problems and potential salt problems.

The first runoff of feedlot flushes much of the readily soluble and transportable salts (11, 12). In a dry season with limited runoff, a normal production of salts is available for movement in the lesser quantities of runoff. If storage of such runoff is continued in a holding pond with a large surface area subject to evaporation, the effluent eventually applied to the soil may have a high salt content.

## Experience with Crop Response

Land application of the effluent from feedlot runoff is the most feasible means of disposal available (15, 16). Land disposal may decrease yield and quality of crops, increase soil salinity, and cause deterioration of soil structure.

A study of effluent disposal was initiated in 1970 at the Springfield site with crops of tall fescue and perennial ryegrass, both overseeded with Ladino clover on a silty clay loam. The three species are well adapted to eastern Nebraska and were chosen for their different tolerances to salt. Tall fescue has good salt tolerance, perennial ryegrass has moderate salt tolerance, and Ladino clover has very low salt tolerance. While periodic measurements of electrical conductivity of the surface soils were made, along with chemical analyses to measure salt accumulation in the soil, it was believed that the differences in salt tolerance of the three species would permit almost immediate detection of harmful salt accumulations in the soil (17).

The four treatments used throughout each growing season were: (1) 5.1 cm (2 in.) of water once each week; (2) 2.5 cm (1 in.) of effluent once each week; (3) 5.1 cm (2 in.) of effluent once each week; and (4) 7.6 cm (3 in.) of effluent once every 2 weeks.

The amounts of water and effluent applied during the three growing seasons (1970-1972) are given in Table 8. Precipitation plus the applications of effluent and water increased the soil-water content at the 2.4-m (2.6-yd) depth on all treatments by the end of July, 1970. This indicated initial water movement through and below the effective root zone of the grasses and clover.

Table 8. FEEDLOT EFFLUENT AND WATER APPLICATIONS TO GRASS AND CLOVER PLOTS, SILTY CLAY LOAM SOIL, SPRINGFIELD, NEBRASKA, 1970-72

| Year | Number of applications | Total depth applied (cm) | Total depth including rainfall[a] (cm) |
|---|---|---|---|
| | 5.1 cm water once each week | | |
| 1970 | 10 | 50.8 | 79.9 |
| 1971 | 18 | 91.4 | 102.7 |
| 1972 | 17 | 86.4 | 111.5 |
| | 2.5 cm effluent, once each week | | |
| 1970 | 10 | 25.4 | 54.5 |
| 1971 | 18 | 45.7 | 57.0 |
| 1972 | 17 | 43.2 | 68.3 |
| | 5.1 cm effluent, once each week | | |
| 1970 | 10 | 50.8 | 79.9 |
| 1971 | 18 | 91.4 | 102.7 |
| 1972 | 17 | 86.4 | 111.5 |
| | 7.6 cm effluent, once every 2 weeks | | |
| 1970 | 5 | 38.1 | 67.2 |
| 1971 | 9 | 68.6 | 79.9 |
| 1972 | 9 | 68.6 | 93.7 |

[a] Rainfall during season of application: 29.1 cm (11.5 in.), July 1-Sept. 30, 1970; 11.3 cm (4.5 in.), June 1-Oct.15, 1971 [40.6 cm (16 in.) normal]; and 25.1 cm (9.9 in.) June 1-Oct. 1, 1972.

The total quantities of solids, nutrients, and salts applied with the various treatments from July 1, 1970, to October 1, 1972, are listed in Table 9. Precipitation totaling 159.8 cm (63 in.) was measured during this period. The 5.1-cm-(2-in.) per-week rate of application supplied 31 metric tons (34.1 tons) of solids and 3,114 kg (6,866 lb) of nitrogen per hectare over the 3 years. More than 1,000 kg (2,205 lb) of N per hectare per season appears to be excessive. However, losses of $NH_4$-N are high immediately after the application of the effluent; only about one-half of the total N applied is available the first year.

The highest-yielding treatments in 1971 were the 2.5 cm (1 in.) of effluent weekly and 7.6 cm (3 in.) of effluent biweekly, with total season yields of 9,440 and 9,440 kg/hectare (8,420 lb/acre), respectively. The 5.1-cm (2-in.) water treatment yielded least-- 8,438 kg/ha. (7,527 lb/acre). For all treatments, average yields decreased while total nitrogen increased with each succeeding harvest. However, total N did not differ significantly between treatments.

The plots were harvested May 31, July 19, September 5, and October 16, 1972. Very little ryegrass or fescue remained to compete with the clover in the spring of 1972. The last three harvests consisted entirely of Ladino clover. In 1972, the 7.6-cm (3-in.) biweekly effluent treatment yielded most, 10,220 kg/ha. (9,116 lb/acre), and the water-irrigated treatment yielded least, 8,460 kg/ha. (7,546 lb/acre). Only at the second cutting, however, did the 7.6-cm (3-in.) effluent treatment yield significantly more (5% level) than did the watered treatment. No other differences were significant for individual cuttings. Because of the dominance of the Ladino clover, paired subplots planted to fescue and ryegrass did not differ significantly. Therefore, the yields and nitrogen contents are summarized for the whole plots in Table 10. For the seven cuttings in 1971-1972, the 7.6-cm (3-in.) biweekly effluent treatment yielded 19,620 kg/ha. (17,501 lb/acre, which was significantly higher than the watered treatment of 16,900 kg/ha. (15,074 lb/acre). None of the other differences were significant.

A maximum of 229 cm (90 in.) of beef feedlot runoff effluent was applied during three growing seasons to the tall fescue, perennial ryegrass, and Ladino clover. No detrimental salt or nutrient accumulations were found in the silty clay loam soil at the end of the period. The effluent applications generally improved forage yields, despite applications in excess of the water requirements of the grasses and clover. Chemical analyses of the forage did not reveal undesirable or toxic contents, and the forage was of excellent quality. Precipitation totaled 160 cm (63 in.) during the period from July 1, 1970, to October 1, 1972.

In the second season, the Ladino clover dominated the stands with the more salt-tolerant grasses. This indicated that undiluted runoff

Table 9. QUANTITIES OF SOLIDS AND NUTRIENTS APPLIED TO GRASS-CLOVER, COCKERILL FEEDLOTS, SPRINGFIELD, NEBRASKA, 1970-72

(kg/ha)

| | Grass-clover | | |
|---|---|---|---|
| | 2.5 cm weekly | 5.1 cm weekly | 7.6 cm biweekly |
| 1970 | | | |
| Total solids | 16,820 | 3,399 | 26,410 |
| Volatile solids | 9,055 | 18,120 | 14,390 |
| Total nitrogen | 902 | 1,803 | 1,434 |
| Total phosphorus | 45 | 90 | 73 |
| Salts | 7,482 | 14,960 | 11,880 |
| 1971 | | | |
| Total solids | 13,710 | 27,420 | 20,560 |
| Volatile solids | 5,925 | 11,860 | 8,892 |
| Total nitrogen | 414 | 829 | 622 |
| Total phosphorus | 196 | 392 | 297 |
| Salts | 4,032 | 8,064 | 6,048 |
| 1972 | | | |
| Total solids | 9,486 | 1,898 | 15,070 |
| Volatile solids | 4,312 | 8,624 | 6,896 |
| Total nitrogen | 241 | 482 | 381 |
| Total phosphorus | 90 | 179 | 146 |
| Salts | 3,366 | 6,726 | 5,342 |
| Total for 3 years, 1970-72 | | | |
| Total solids | 40,020 | 80,040 | 55,670 |
| Volatile solids | 19,290 | 38,600 | 30,130 |
| Total nitrogen | 1,557 | 3,114 | 2,436 |
| Total phosphorus | 330 | 661 | 515 |
| Salts | 14,880 | 29,750 | 23,270 |

Table 10. FORAGE YIELDS AND TOTAL NITROGEN CONTENTS, GRASS AND CONTENTS, GRASS AND CLOVER EFFLUENT DISPOSAL PLOTS, SPRINGFIELD, NEBRASKA, 1971-1972 [a]

| Date of harvest | Treatment | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2.5 cm effluent weekly | | 5.1 cm effluent weekly | | 5.1 cm water weekly | | 7.6 cm effluent biweekly | |
| | Yield | Total N | Yield | Total N | Yield | Total N | Yield | Total N |
| | kg/ha. | % | kg/ha. | % | kg/ha. | % | kg/ha. | % |
| June 2, 1971 | 3,377 | 2.10 | 4,112 | 2.26 | 3,783 | 2.89 | 4,061 | 1.92 |
| July 19, 1971 | 3,184 | 2.72 | 3,138 | 2.98 | 2,495 | 3.02 | 3,409 | 2.82 |
| Aug. 24, 1971 | 2,293 | 3.47 | 2,192 | 3.62 | 2,159 | 3.47 | 1,930 | 3.64 |
| Total - 1971 | 8,854 | | 9,442 | | 8,438 | | 9,400 | |
| May 31, 1972 | 2,726 | 3.42 | 3,098 | 2.85 | 2,741 | 3.08 | 3,398 | 2.45 |
| July 19, 1972 | 2,583 | 2.93 | 2,741 | 2.90 | 2,376 | 2.87 | 3,283 | 2.70 |
| Sept. 5, 1972 | 2,205 | 2.69 | 2,100 | 2.90 | 1,997 | 2.89 | 1,939 | 1.93 |
| Oct. 16, 1972 | 1,541 | 2.39 | 1,500 | 2.24 | 1,347 | 2.42 | 1,599 | 2.42 |
| Total - 1972 | 9,055 | | 9,432 | | 8.460 | | 10,220 | |
| Total - 1971-72 | 17,910 | | 18,870 | | 16,900 | | 19,620 | |

[a] Grasshopper damage in 1970 precluded meaningful forage data

effluent in this area can be used safely to irrigate a crop of low salt-tolerance.

Results from this study indicate that the water and nutrients in feedlot runoff effluent can be utilized by perennial hay crops.

Corn also was irrigated with both feedlot runoff effluent and water on the silty clay loam at Springfield. Five treatments were replicated three times in a completely random design. The treatments were weekly applications of 3.8 cm (1.5 in.) of effluent, 3.8 cm (1.5 in.) of water, 7.6 cm (3 in.) of effluent, and 7.6 cm (3 in.) of water. About 1 month after the corn was planted, irrigation furrows were formed between the corn rows, and the weekly irrigation applications were begun. Irrigation was discontinued when the corn began to dent in early September (18).

The total quantities of solids, nutrients, and salts applied to corn plots receiving maximum rates of effluent application are shown in Table 11. The corn grain and stover yields for the various treatments are reported in Table 12.

The effluent-irrigated treatments yielded more grain and stover than corresponding water-irrigated treatments and more than the check treatment each of the 3 years. These differences, however, were not statistically significant (5% level). Three years' yield data were analyzed as split plots in time. The 3-year average grain yields showed highly significant differences between the check treatment and all irrigation treatments. The effluent treatments averaged 690 to 815 kg/ha. (615 to 727 lb/acre) more than the corresponding water treatments. While these differences were not significant at the 5% level, the difference between the 3.8-cm (1.5-in.) effluent and 3.8-cm water treatments was significant at the 10% level. The average for the two effluent treatments was almost identical, as were the two water treatments. The 3-year average stover yields were not different among the four irrigation treatments. The effluent-irrigated stover yielded more than the check, but the water-irrigated stover did not.

Chemical analyses of the stalks did not reveal nitrate contents which could be related to the effluent treatments.

Forage sorghum was irrigated with feedlot runoff effluent and with water at the Springfield site during 1971 and 1972 (15, 16, 19).

A series of five treatments with three replications of each treatment were used. The water and effluent applications were made in irrigation furrows as with corn. The treatments are as follows: (1) check plot, no application; (2) 2.5 cm (1 in.) water every 5 to 7 days if no rain, late June to harvest; (3) 5.1 cm (2 in.) water every 5 to 7 days if no rain, late June to harvest; (4) 2.5 cm (1 in.) effluent every 5 to 7

Table 11. TOTAL QUANTITIES OF SOLIDS, NUTRIENTS AND SALTS APPLIED TO CORN PLOTS RECEIVING MAXIMUM RATES OF EFFLUENT APPLICATION SPRINGFIELD, NEBRASKA, 1970-72[a]
(kg/ha.)

| Year | Total solids | Volatile solids | Total nitrogen | Total phosphorus | Total salts |
|---|---|---|---|---|---|
| 1970[b] | 21,730 | 11,760 | 1,198 | 56 | 9,677 |
| 1971[c] | 18,206 | 7,280 | 504 | 336 | 5,219 |
| 1972[d] | 16,740 | 7,616 | 414 | 146 | 5,757 |
| Total 1970-1972 | 56,730 | 26,666 | 2,116 | 538 | 20,653 |

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[a] Quantities of solids, nutrients, and salts for the lower rates of effluent applicaton are one-half of the values tabulated for the maximum rates of effluent application.

[b] Values for 11 effluent applications of 5.1 cm (2 in.) each.

[c] Values of 8 effluent applications of 7.6 cm (3 in.) each.

[d] Values for 10 effluent applications of 7.6 cm (3 in.) each.

Table 12. CORN GRAIN AND STOVER YIELDS FROM EFFLUENT DISPOSAL PLOTS, COCKERILL FEEDLOTS, SPRINGFIELD, NEBRASKA, 1972

| Irrigation treatments | Corn grain yields, kg/ha.@15.5% moisture | | | | Corn stover yields, kg/ha.dry matter | | | |
|---|---|---|---|---|---|---|---|---|
| | 1970 | 1971 | 1972 | 3-yr average | 1970 | 1971 | 1972 | 3-yr average |
| 3.8 cm effluent | 10,560 | 6,285 | 11,950 | 9,602 | 8,524 | 9,470 | 11,880 | 9,957 |
| 3.8 cm water | 9,107 | 5,883 | 11,420 | 8,806 | 7,665 | 8,595 | 11,460 | 9,241 |
| 7.6 cm effluent | 10,780 | 6,987 | 11,260 | 9,671 | 9,452 | 8,780 | 11,660 | 9,964 |
| 7.6 cm water | 9,433 | 6,617 | 10,880 | 8,975 | 7,977 | 8,502 | 11,590 | 9,358 |
| Check | 6,567 | 5,808 | 10,980 | 7,784 | 7,085 | 8,072 | 8,695 | 7,951 |

days if no rain, late June to harvest; and (5) 5.1 cm (2 in.) effluent every 5 to 7 days if no rain, late June to harvest.

The characteristics of the effluent and total quantities of nutrients and solids applied to the forage with the 5.1-cm (2-in.) effluent application are given in Table 13. The yields of the forage are presented in Table 14.

The 2.5-cm (1 in.) effluent treatment produced the highest yields in each of the 2 years. The forage yield from the 2.5-cm effluent treatment was significantly higher than all other treatments in 1972. The addition of 2.5 cm effluent per week (25 cm annually) may be the optimum effluent application rate for forage production in northeastern Nebraska.

Nitrate-nitrogen contents of plan samples for each respective treatment are presented in Table 12. All treatments showed high $NO_3$-N concentrations in 1971. These high $NO_3$-N concentrations, however, could not be attributed to effluent loading; dry weather and carry-over of N from 1970 are possible reasons.

The $NO_3$-N content of plant samples collected from the 1972 harvest shows a great reduction in $NO_3$-N in all treatments as compared with 1971. Cool, rainy weather during the 1972 growing season and lower N soil reserve are factors partially accountable for this observation. Both effluent treatments showed higher $NO_3$-N concentration than plant samples from the water treatments. Increased effluent loading resulted in increasing $NO_3$-N accumulations. The butt samples from plots receiving 5.1 cm (2 in.) of effluent in 1972 were significantly higher in $NO_3$-N than those harvested from the 5.1-cm (2-in.) water treatment (Table 15).

All plant samples were anlayzed for Ca, Mg, Na, and K content. No apparent treatment differences could be observed over the 2-year study. Potassium concentrations were higher in all treatment samples collected in 1971, ranging from 2.13% (2.5 cm effluent) to 2.30% (5.1 cm water), as compared with the range of 1.75% to 1.93% in 1972. The differences were not related to treatment.

The sodium-bicarbonate-extractable P content of the top 10.2 cm (4 in.) of soil cores taken in 1971 and 1972 was determined. An additive effect was observed from the application of feedlot effluent. The P increase was observed only in the surface soil samples. Analyses of soil cores, taken to a depth of 2.4 m (2.6 yd) revealed little variation of P levels below the 10.2-cm (4-in.) soil depth between treatments.

The P addition from the applied effluent was significantly higher in the 5.1-cm (2-in.) effluent treatment when compared with both water treatments in 1972.

Table 13. CHARACTERISTICS OF THE EFFLUENT AND TOTAL QUANTITIES OF NUTRIENTS AND SOLIDS APPLIED TO FORAGE SORGHUM PLOTS IN 1971 AND 1972, SPRINGFIELD, NEBRASKA

|  | Volatile solids % | Ash % | Total N ppm | $NH_4$-N, ppm | $NO_3$-N, ppm | $NO_2$-N, ppm | Total P ppm | pH | Electrical conductivity, mmhos/cm |
|---|---|---|---|---|---|---|---|---|---|
| 1971 |  |  |  |  |  |  |  |  |  |
| Average | 0.11 | 0.12 | 71 | 66 | 1.13 | 0.08 | 34 | 8.9 | 1.51 |
| kg/ha. from 5.1-cm applications (56 cm) | 5924 | 6764 | 399 | 366 | 12.3 | 0.45 | 192.6 |  |  |
| 1972 |  |  |  |  |  |  |  |  |  |
| Average | 0.09 | 0.11 | 48 | 21 | 4.72 | 0.04 | 18 | 9.0 | 1.26 |
| kg/ha. from 5.1-cm application (51 cm) | 4424 | 5432 | 242 | 106.4 | 23.5 | 1.20 | 90.7 |  |  |

Table 14. FORAGE SORGHUM YIELDS FOR 1971 and 1972
(metric tons dry matter/hectare)

| Treatment | 1971 | 1972 |
|---|---|---|
| Check | 15.2 | 15.5 |
| 2.5 cm water | 16.1 | 15.5 |
| 5.1 cm water | 17.2 | 14.8 |
| 2.5 cm effluent | 17.5 | 18.1 |
| 5.1 cm effluent | 17.0 | 15.5 |

Duncan Multiple Range Test of sorghum yields
at the 5% level of significance*

| 1971 | | 1972 | |
|---|---|---|---|
| Treatment | Yield | Treatment | Yield |
| 2.5 cm effluent | 17.5 a | 2.5 cm effluent | 18.1 a |
| 5.1 cm water | 17.2 a | 5.1 cm effluent | 15.5 b |
| 5.1 cm effluent | 17.0 a | 2.5 cm water | 15.5 b |
| 2.5 cm water | 16.1 a | Check | 15.5 b |
| Check | 15.2 a | 5.1 cm water | 14.8 b |

*Note: Yields followed by a different letter (a or b) were significantly different at the 5% level.

TABLE 15. NITRATE-N CONTAINED IN FORAGE SORGHUM HARVESTED IN 1971 AND 1972 (ppm)

| Treatment | $NO_3$-N [a] | | | |
|---|---|---|---|---|
| | 1971 | | 1972 | |
| | Butt | Top | Butt | Top |
| Check | 11,700 | 3,100 | 6,000 | 2,090 |
| 2.5 cm water | 11,300 | 4,380 | 5,400 | 1,680 |
| 5.1 cm water | 10,400 | 4,220 | 4,700 | 1,510 |
| 2.5 cm effluent | 10,800 | 3,900 | 6,100 | 1,840 |
| 5.1 cm effluent | 10,500 | 4,200 | 7,050 | 2,020 |

[a] $NO_3$-N calculated on 100% dry-weight basis

Duncan Multiple Range Test of $NO_3$-N in butt samples harvested in 1972, at the 5% level of significance

| Treatment | $NO_3$-N (ppm) |
|---|---|
| 5.1 cm effluent | 7,050 |
| 2.5 cm effluent | 6,100 |
| Check | 6,000 |
| 2.5 cm water | 5,400 |
| 5.1 cm water | 4,700 |

The $NO_3$-N levels in 2.4 m (2.6 yd) soil cores showed an overall decline during the 2-year study. A sharper decline in $NO_3^-N$ was observed in 1972 when compared with 1971. The higher amounts of natural precipitation, in combination with continued irrigation, may have facilitated leaching of $NO_3$-N in 1972. The fact that the effluent treatments showed less decline in $NO_3$-N when compared with the water treatments indicates that some of the effluent-added N was accumulating as $NO_3$-N.

Additional N losses via plant uptake, volatilization, and denitrification may have counterbalanced the N addition in the effluent treatments. Higher precipitation occurring in 1972 again may have been the influencing factor when these losses are considered.

Soil pH and electrical conductivity analyses were conducted on soil samples to a depth of 20 cm (7.9 in). Slight increases in both soil pH and electrical conductivity were observed on effluent-treated soil. The increases were slight, however, and would cause no detrimental effects on crop production.

Analyses of soil solution samples showed an increase in concentration of Ca, Na, and K ions in effluent-treated soil. These cations were increasing in soil solution samples collected at a depth of 61 cm (24 in). Samples collected at a depth of 1.8 m (2 yd) did not follow this pattern and showed little difference among treatments.

The increase in Ca, Na, and K observed in soil solution samples from effluent treatments may account for the increase in soil pH and electrical conductivities. The increases in pH and electrical conductivities were slight but did reflect some salt addition due to effluent application.

The physical properties of the soil on which the forage sorghum was produced with the applications of runoff effluent were also investigated. Soil samples from 0- to 10-cm (3.9-in) depths were taken for bulk density, particle size analysis, moisture release, hydraulic conductivity of disturbed and undisturbed samples, and wet-aggregate analysis. These soil samples were taken just before, midway, and at the end of each irrigation season. The effluent treatments produced no differences in bulk density, soil water storage and release, or in wet-aggregate analyses. Significant differences were measured for hydraulic conductivity of disturbed and undisturbed soil samples.

The hydraulic conductivity values on disturbed soil surface samples were recorded at the 2- and 24-hour intervals. The ratios of the 3 hr: 24 hr values were calculated. A small ratio indicates low stability of aggregates in water and, hence, the physical condition of soil has deteriorated. Significant differences were discovered at the 1% level for treatments of nonirrigation vs others and water vs effluent. A decrease in hydraulic conductivity was noted for the effluent plots as compared with the nonirrigated plots. This is probably associated with the clogging of pores by the colloidal particles and the dispersion of soil by the sodium and potassium in the effluent. A decrease could also occur from organic matter in the effluent.

An important fact was also noted in comparing the hydraulic conductivities for the fall 1971 with spring 1972 samples. The fall samples show a definite decrease in hydraulic conductivity ratios of effluent plots compared with nonirrigated plots, while in the spring, the ratio values are nearly the same for all treatments. Evidently, over the winter period the effects of effluent are reduced to nearly normal, probably through leaching of the salts by winter rains. The freezing and thawing of the soil also increases the water stability of aggregates.

Percolate samples, representing the first 50 ml, were collected while the hydraulic conductivities were analyzed. A chemical analysis was conducted for $Na^+$, $K^+$, $Cl^-$, $NO_3$-N, $NH_4$-N, pH, and electrical conductivity. The highest value sodium content was 116 ppm for the 5.1-cm (2-in.) effluent plots after the final irrigation in 1971. This value does not create any immediate problems in deterioration of the physical properties of the soil. All sodium values in the spring of 1972 were lower than the previous fall. These were reduced by leaching over the nonirrigation season.

The high-effluent plots recorded the largest potassium content, with 123 ppm after the first irrigation season being the highest. Leaching during the nonirrigation season reduced the potassium values by at least half.

Chloride contents were calculated and show rather large values for effluent plots in 1971, but very reduced values in 1972. Precipitation during the nonirrigation season caused the leaching of $Cl^-$, as the chloride ions are very susceptible to leaching.

The results for $NH_4$-N, $NO_3$-N, and pH show no serious changes from application of effluent, as the values are all low or normal.

The highest electrical conductivities (EC) for the percolate samples were obtained on the effluent plots. These values were at least double the values of the water and no-irrigation (check) plots, but still low enough not to be a salt problem. The EC of the percolate from the effluent plots decreased during the nonirrigation season of 1971-72. The decreased EC shows that some salts were probably leached during this period.

Feedlot runoff effluent is a highly variable, low-grade fertilizer. However, large and frequent applications can supply much of the nutrient needs of many crops. Annual applications up to 91.4 cm (36 in.) on grass-Ladino clover and 76.2 cm (30 in.) on corn have not decreased, and sometimes increased, yields. Good growth of the Ladino clover, a low salt-tolerant crop, indicates salt accumulation in the soil is not a problem.

## COLORADO CONDITIONS

The limited runoff is of such composition that it must be kept out of surface waters, and disposal on arable land is preferred. No data are available concerning direct application to crops, but judging from comparisons made of the compositions of Nebraska and Colorado runoff, the Colorado material would have to be diluted with irrigation water to lower the conductivity to acceptable values if such disposal were contemplated.

# SECTION VIII

# COMPOSITION OF SOIL SOLUTION AND SOIL ATMOSPHERE BENEATH FEEDLOTS

## NEBRASKA

### Solution and Gas Samples from Caissons

Prior to these studies, it was believed most feedlots contaminated soil profiles and water tables beneath them. The data presented here were obtained from soil solution and soil gas samples collected from caissons, vacuum lysimeters, and soil cores. Soil solution samples were used to assess pollutants that may be moving through the soil profile and soil gas samples were used to determine the reduction status of the soil profile.

At the Central City site, there were two caissons in the feedlot and one in an adjacent cropped field. At the Springfield site, there was one caisson in the slope, one in the basin of the feedlot, and one in an adjacent cropped field. Caissons design and use have been described (5).

Data from the Central City feedlot (Table 16) show a comparison of average yearly concentrations of the N compounds beneath a feedlot and

Table 16. AVERAGE YEARLY CONCENTRATIONS OF SOME NITROGEN COMPOUNDS IN THE SOIL SOLUTION BENEATH A FEEDLOT AND A CROPPED FIELD (μg/ml)

| Depth, cm | $NO_3$-N | $NH_4$-N | Total N |
|---|---|---|---|
| Feedlot | | | |
| 15.0 | 32.5 | 538.6 | 713.4 |
| 45.7 | 0.1 | 30.9 | 40.6 |
| 76.0 | 0.3 | 1.9 | 8.9 |
| 106.6 | 0.6 | 1.0 | 5.6 |
| Field | | | |
| 30.5 | 8.1 | 8.3 | 17.1 |
| 61.0 | 7.2 | 0.9 | 20.4 |
| 91.4 | 7.8 | 1.1 | 12.9 |

a cropped field. The feedlot $NO_3$-N values at 45.7 cm (18 in.) and below appeared lower than those obtained from the cropped field. The $NH_4$-N samples from the feedlot and field were similar at 76 cm (30 in.) and below. At these depths, total-N values seem to be higher in the field than in the feedlot. However, the total-N values include the $NO_3$-N values, which were higher in the cropped field. If the $NO_3$-N values are subtracted, the total-N values from 76 cm (30 in.) and below in the feedlot and the cropped field would be comparable.

The soil water samples indicate this feedlot contributes low amounts of $NO_3$-N, $NH_4$-N, and soluble N-containing compounds to the groundwater. Samples from the feedlot obtained at the 15-cm depth were higher in these compounds; however, at the 76-cm depth, the levels appeared as low as, or lower than, comparable field samples (20).

Table 17 shows the average gas composition of the soil atmosphere at various depths beneath the Central City feedlot and in an adjacent cornfield for a 1-year period. High $CH_4$ and $CO_2$ were found beneath the feedlot. As sample depth increased, $CH_4$ values increased to about 18% from the 91.4-cm (36-in.) depth to 137-cm (54-in.) depth. These results indicate vigorous $CH_4$ production was taking place in the feedlot soil profile. Because $CH_4$ is lighter than air, only limited downward diffusion would be expected; thus, some $CH_4$ was probably produced near the 137-cm (36-in.) level. Single values at the 152.4-cm (60-in.) depth of up to 55% $CH_4$ and 40% $CO_2$ were recorded. Lower concentrations of $CH_4$ at the surface hint of $CH_4$ diffusion through the surface and/or inhibition of $CH_4$-producing bacteria by $O_2$. Production of the quantities of $CH_4$ detected beneath this feedlot indicates the presence of appreciable metabolizable organic matter in the soil profile. This conclusion is made on the basis that $CH_4$ bacteria generally require specific organic substrates (21). As would be expected, $O_2$ concentrations are much reduced because $CH_4$ production takes place only under anaerobic conditions. Where $CH_4$ was high in individual samples, $O_2$ was very low or zero. Table 17 also shows the cropped field values. No $CH_4$ was detected at any time, and $O_2$ and $N_2$ values were close to atmospheric. As expected, $CO_2$ values in the field soil profile were higher than atmospheric values (22).

The soil solution data from the Central City site show the feedlot is not contaminating the shallow groundwater; therefore, the answer is one of management. This feedlot is used continuously through the year. The surface of the feedlot, when the manure pack is intact, has a low infiltration rate (4). Thus, it seems that if a feedlot is kept well stocked and manure-packed, soil interface is not disturbed, only limited organic matter and $NO_3$-N will reach the underground water supply (20). Also, the feedlot soil profile should remain anaerobic. The gas data from this site show the feedlot profile is reduced, and this indicates denitrification can occur (22). Investigations at this site show that groundwater pollution from an active feedlot surface is not a problem.

Table 17. AVERAGE SOIL ATMOSPHERE COMPOSITION AT VARIOUS SOIL DEPTHS BENEATH A FEEDLOT AND CROPPED FIELD FOR A 1-YEAR PERIOD
(% by volume)

| Depth, cm | $CO_2$ | $O_2$ | $N_2$ | $CH_4$ | Total |
|---|---|---|---|---|---|
| Feedlot | | | | | |
| 30.5 | 15.0 | 9.5 | 66.0 | 8.0 | 98.5 |
| 45.7 | 12.5 | 9.5 | 68.5 | 8.0 | 98.5 |
| 61.0 | 15.0 | 7.5 | 65.0 | 11.5 | 99.0 |
| 76.0 | 23.0 | 4.5 | 45.0 | 27.5 | 100.0 |
| 91.4 | 18.5 | 5.0 | 58.5 | 18.0 | 100.0 |
| 106.6 | 18.0 | 5.0 | 57.5 | 17.5 | 98.0 |
| 122.0 | 18.5 | 5.0 | 56.5 | 18.5 | 98.5 |
| 137.0 | 21.0 | 6.0 | 52.0 | 20.0 | 99.0 |
| Cropped field | | | | | |
| 30.5 | 2.0 | 18.0 | 79.0 | 0 | 99.0 |
| 61.0 | 2.0 | 18.0 | 80.0 | 0 | 100.0 |
| 91.4 | 2.5 | 18.0 | 79.0 | 0 | 99.5 |
| 122.0 | 2.5 | 18.0 | 79.0 | 0 | 99.5 |
| 152.4 | 1.0 | 19.0 | 79.0 | 0 | 99.0 |

(These data show this feedlot soil profile is favorable for denitrification)

Figure 11 shows $NO_3$-N increased in the basin at the Springfield site through the 122-cm (48-in.) depth during the first 3 months of sampling (11 months of operation). Values up to 70 ppm $NO_3$-N were recorded at 30.5 cm (12 in.) while samples at 61 and 122 cm (24 and 58 in.) peaked at about 40 ppm $NO_3$-N. After 4 months, $NO_3$-N increased to approximately 40 ppm at 152.4 cm (60 in.) and was decreasing at 122 cm (48 in.). After 13 months of sampling (21 months of operation), soil water nitrate had decreased to 1.4, 10, and 12.5 ppm $NO_3$-N at 61, 122, and 152.4 cm (24, 48 and 60 in.), respectively. Near the end of the study, the soil water samplers ceased to function at 30.5 cm (12 in.). Soil water nitrate at 183, 244, and 305 cm (72, 96, and 120 in.) was relatively constant at respective averages of <1, 15, and 10ppm $NO_3$-N (Figure 12). Two unexplained high values caused the rise at 244 cm (96 in.) in March. These data show nitrate was not carried below 152.4 cm (60 in.) (23).

The decrease in nitrate during the latter part of the sampling period coincided with an increase in $CO_2$ and a decrease in $O_2$ (Figure 13). The $CO_2$ was highest between 61 and 305 cm (24 and 120 in.). These data indicate establishment of reducing conditions beneath the basin. Reducing conditions, coupled with the nitrate decrease, indicate that denitrification was occurring. Nitrate-N of the well samples was below the U. S. Public Health Service limit of 10 ppm (24).

These studies indicate if a feedlot is stocked continuously, and when cleaned, if the dense soil-manure interface layer is not removed, pollution of groundwater should not occur.

## COLORADO

### Solutions and Gas Samples from Caissons

Cased, dry wells or caissons were installed in a commercial feedlot (Ashlind Feeders, Inc., 9.3 km (5.8) miles northeast of Fort Collins) late in 1970. One caisson was installed near the feedbunk (low elevation in a pen), one caisson was installed near the center of the same pen (at a higher elevation), and one in an adjacent alfalfa field for comparison observations. Soil water tensions, soil temperatures, soil gases were monitored. In addition, water in the general area from irrigation wells, irrigation canals, drainage canals, and domestic wells was analyzed for comparison with the caisson data.

Data are still being gathered and analyzed, and Tables 18 through 25 present the current results.

Tables 18-20 present the composition of extracted soil solutions obtained by porous ceramic cups and the water samples for comparison.

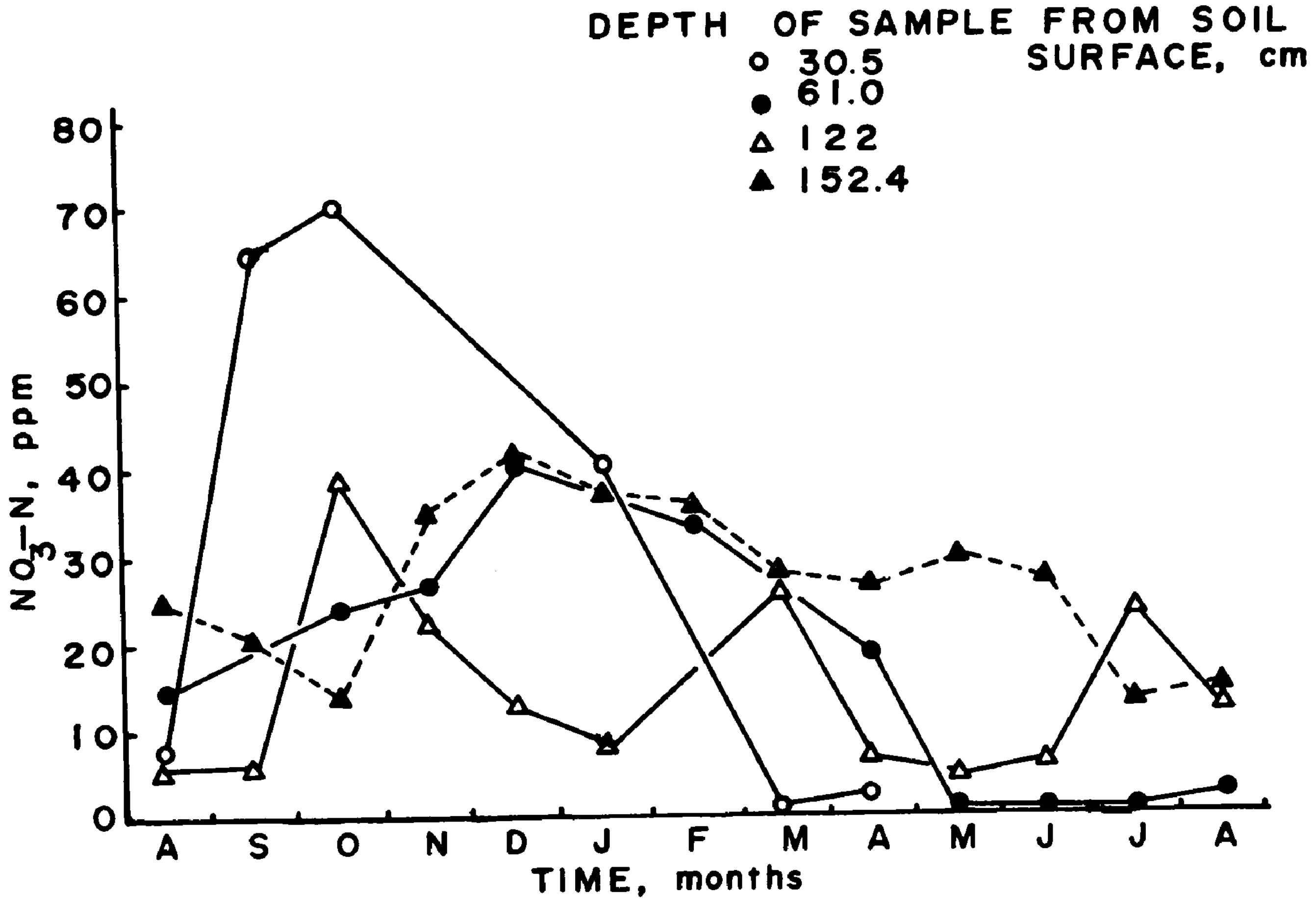

Figure 11. Average $NO_3$-N levels in the soil solution extracted from the broad-basin terraced feedlot at increments of depth and time, Springfield, Nebraska, 1970-1971.

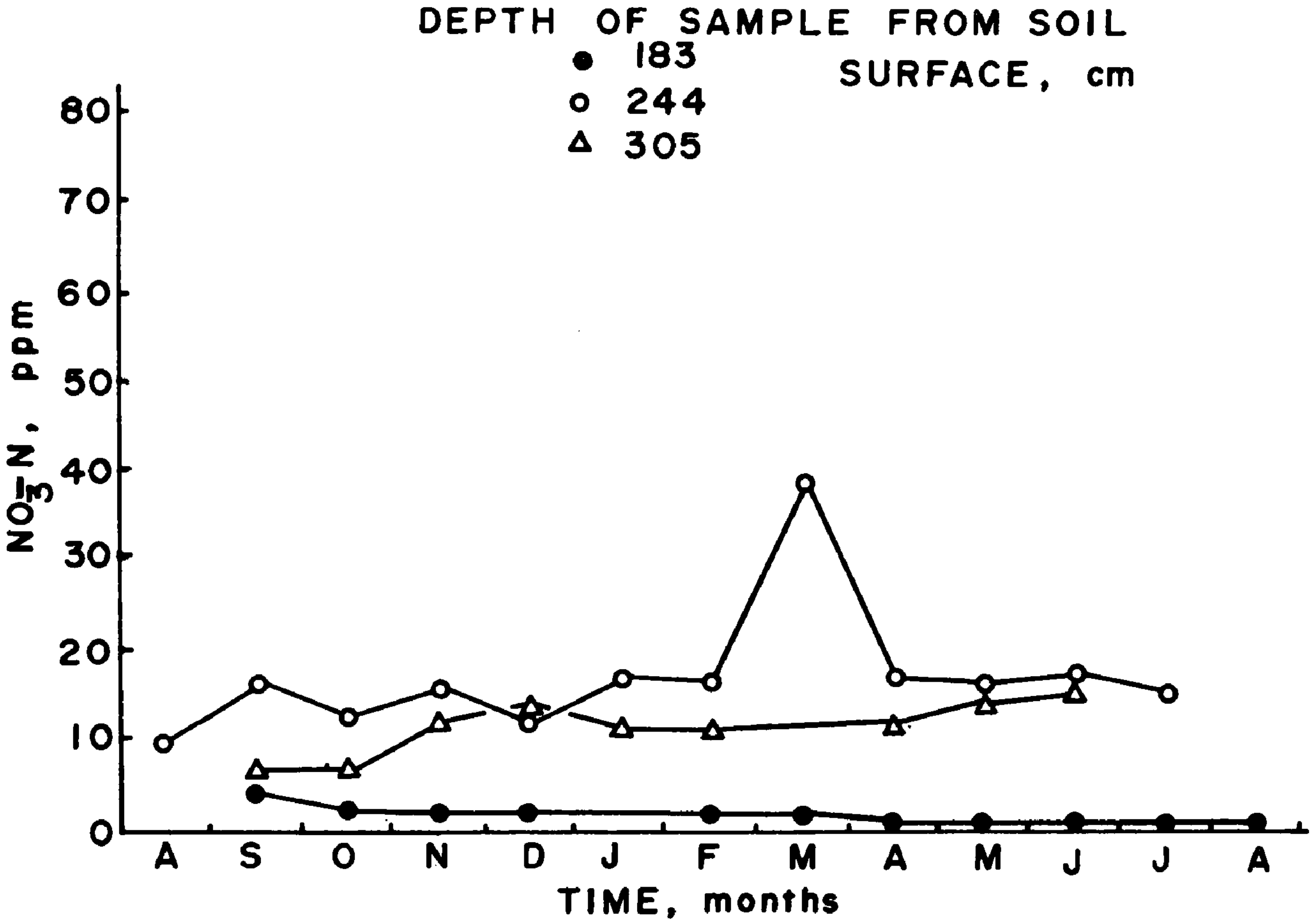

Figure 12. Average $NO_3$-N levels in the soil solution extracted from the broad-basin terraced feedlot at increments of depth and time, Springfield, Nebraska, 1970-1971.

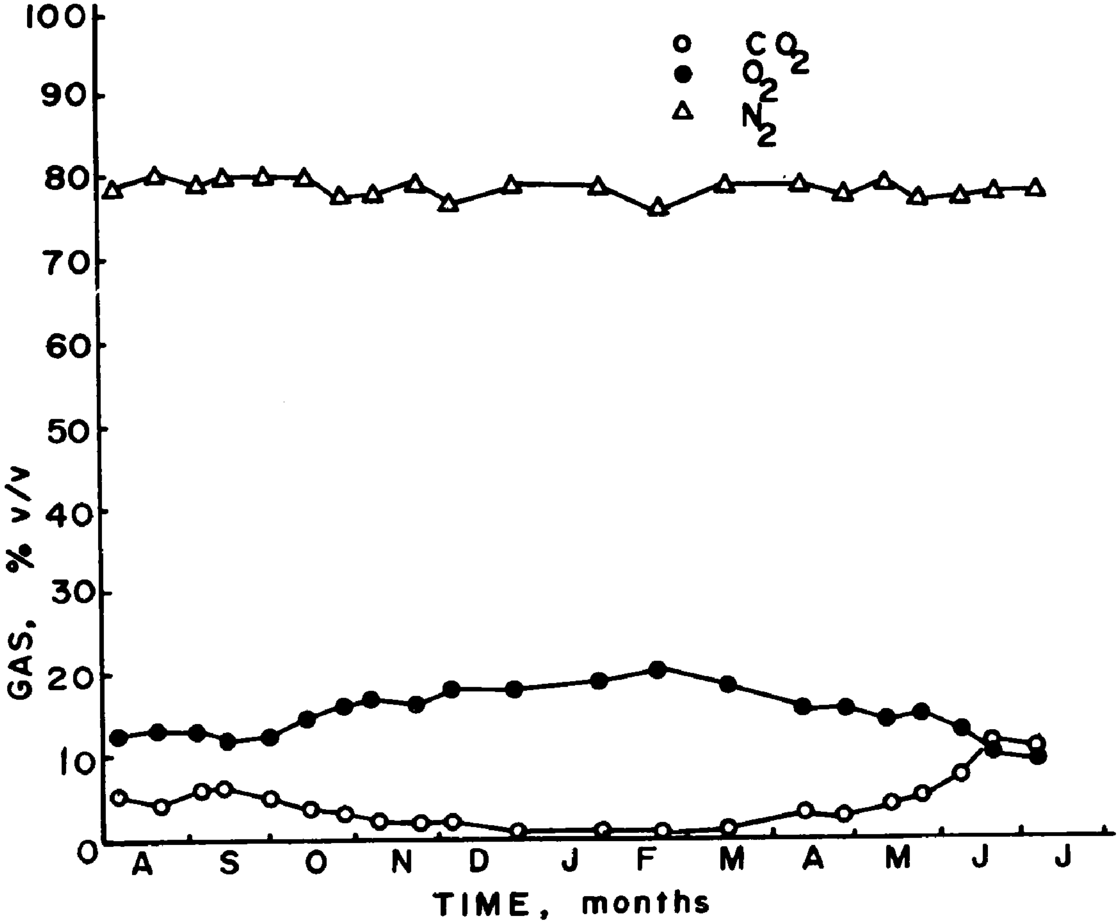

Figure 13. Average soil-gas composition from 1 to 10 ft. beneath the basin, broad-basin terraced feedlot, Springfield, Nebraska, 1970-1971.

Table 18. NITRATE AND NITRITE NITROGEN AND ECLECTRICAL CONDUCTIVITY OF SOIL SOLUTIONS[a] OBTAINED FROM CAISSONS AT ASHLIND FEEDERS, INC., FORT COLLINS, COLORADO

| Depth, cm | $NO_3$-N, ppm | | | $NO_2$-N, ppm | | | EC, mmhos/cm @ 25°C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Alfalfa[b] | Bunk | Center | Alfalfa | Bunk | Center | Alfalfa | Bunk | Center |
| 15 | 28 | 1 | 1700 | 0.035 | 0.230 | 2.000 | 3.4 | 6.5 | 23.6 |
| 61 | 12 | 2 | 200 | 0.040 | 0.096 | 0.093 | 4.6 | 2.6 | 6.6 |
| 91 | 3 | 2 | 78 | 0.026 | 2.600 | 0.180 | 6.4 | 4.6 | 5.6 |
| 183 | 3 | 0 | 11 | 0.030 | 0.012 | 0.140 | 6.9 | 4.3 | 3.8 |
| 274 | 3 | 3 | 16 | 0.025 | 0.200 | 0.130 | 9.9 | 4.4 | 4.4 |
| Wt.[b] | 2 | 7 | 11 | 0.023 | 0.060 | 0.066 | 6.9 | 4.0 | 4.0 |

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[a] Mean values for samples obtained in 1971, 1972, and 1973

[b] Soil solutions obtained from water table or as low as possible in the caisson

Table 19. CHEMICAL OXYGEN DEMAND, PHOSPHATE, AND pH of SOIL SOLUTIONS[a] OBTAINED FROM CAISSONS AT ASHLIND FEEDERS, INC., FORT COLLINS, COLORADO

| Depth, cm | COD, $mgO_2/l$ | | | $PO_4^3$, ppm | | | pH | | |
|---|---|---|---|---|---|---|---|---|---|
| | Alfalfa | Bunk | Center | Alfalfa | Bunk | Center | Alfalfa | Bunk | Center |
| 15 | 79 | | | 0.29 | | | 8.2 | 7.9 | 8.1 |
| 61 | 72 | 290 | 160 | 0.45 | 0.51 | 0.17 | 8.2 | 7.9 | 8.1 |
| 91 | | 320 | 120 | 0.64 | 0.66 | 0.12 | 8.5 | 8.0 | 8.2 |
| 183 | 86 | 84 | 140 | 0.19 | 0.21 | 0.14 | 8.4 | 8.2 | 8.0 |
| 274 | 180 | 92 | 88 | 0.17 | 0.12 | 0.14 | 8.6 | 8.1 | 8.1 |
| Wt.[b] | 130 | 50 | 37 | 0.18 | 0.13 | 0.15 | 8.6 | 8.1 | 8.1 |

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[a] Mean values for samples obtained in 1971, 1972, and 1973.

[b] Soil solutions obtained from water table or as low as possible in the caisson.

Table 20. NITRATE AND NITRITE NITROGEN, ELECTRICAL CONDUCTIVITY, CHEMICAL OXYGEN DEMAND, PHOSPHATE, AND pH OF WATER SAMPLES OBTAINED FROM SEVERAL SOURCES IN THE AREA OF THE CAISSONS AT ASHLIND FEEDERS, INC., FORT COLLINS, COLORADO

| Site Description | $NH_3$-N ppm | $NO_2$-N ppm | EC mmhos/cm | COD $mgO_2/1$ | $PO_4^3$ ppm | pH |
|---|---|---|---|---|---|---|
| Drainage from alfalfa | 2.5 | 0.032 | 2.4 | 30 | 0.06 | 7.9 |
| Drainage from cultivated field | 4.6 | 0.052 | 3.7 | 40 | 0.08 | 7.8 |
| Canal connecting reservoirs | 3.4 | 0.031 | 2.5 | 60 | 0.20 | 8.1 |
| Drainage from pasture | 0.2 | 0.0 | 1.0 | 50 | 0.08 | 8.0 |
| Irrigation well | 1.6 | 0.0 | 2.3 | 40 | 0.06 | 8.1 |
| Cattle pen water tank | 0 | 0.0 | 0.4 | 1100 | 0.62 | 7.1 |

Table 21. CHARACTERISTICS OF SOIL TAKEN FROM NEAR THE CENTER CAISSON AT ASHLIND FEEDERS, INC. FORT COLLINS, COLORADO

| Depth cm | Water Content, % DWB[a] | Soil Solution | Oven-dry Soil Basis | | |
|---|---|---|---|---|---|
| | | $NO_3$-N + $NO_2$-N ppm | $NO_3$-N + $NO_2$-N ppm | $NH_4$-N ppm | pH |
| 0 -7.6 | 10.0 | 0.0 | 0.0 | 568.6 | 8.43 |
| 76 -15.2 | 11.6 | 79.4 | 9.2 | 221.2 | 7.75 |
| 15.2-22 | 12.6 | 109.0 | 13.7 | 34.6 | 7.74 |
| 22 - 30 | 12.6 | 80.9 | 10.2 | 5.3 | 7.78 |
| 30 - 38 | 14.0 | 67.4 | 9.4 | 2.7 | 7.82 |
| 38 - 46 | 16.1 | 54.1 | 8.7 | 3.2 | 7.88 |
| 46 - 53 | 16.1 | 34.2 | 5.5 | 1.8 | 7.89 |
| 53 - 61 | 15.6 | 32.2 | 5.0 | 4.6 | 7.90 |

[a] Dry weight basis

Table 22. SOIL WATER TENSIONS (CENTIBARS) AS QUARTERLY AVERAGES FOUND IN THE ALFALFA CAISSON AT ASHLIND FEEDERS, INC. FORT COLLINS, COLORADO

| Depth | 1971 | | 1972 | | | | 1973 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| cm | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 15 | 40.2 | 19.6 | 25.0 | 32.2 | 43.8 | 9.8 | 12.2 | 19.1 | 22.1 | 15.2 |
| 61 | 45.5 | 39.2 | 14.6 | 36.3 | 17.2 | 0.0 | 18.8 | 27.2 | 46.1 | 31.1 |
| 91 | 59.5 | 66.8 | 46.1 | 44.5 | 29.6 | 0.0 | 4.7 | 26.5 | a | 30.8 |
| 183 | 24.5 | 25.0 | 27.0 | 27.0 | 48.8 | 23.0 | 17.0 | 15.7 | 17.2 | 22.2 |
| 274 | 24.7 | 26.5 | 31.4 | 35.7 | 55.9 | 57.6 | 31.0 | 27.6 | 23.1 | 23.5 |

[a] Tension exceeded 70 centibars and water films establishing tension were lost.

Table 23. SOIL WATER TENSIONS (CENTIBARS) AS QUARTERLY AVERAGES FOUND IN THE BUNK CAISSON AT ASHLIND FEEDERS, INC., FORT COLLINS, COLORADO

| Depth | 1971 | | 1972 | | | | 1973 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| cm | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 15 | 51.0 | 57.0 | 53.6 | 51.6 | 46.7 | 53.9 | 48.6 | 46.1 | 38.4 | 46.4 |
| 16 | 39.6 | 51.4 | 54.0 | 50.8 | 44.0 | 48.0 | 48.3 | 44.9 | 35.0 | 41.5 |
| 91 | 35.2 | 31.7 | 33.9 | 33.7 | 30.9 | 31.6 | 22.5 | 23.0 | 20.8 | 20.4 |
| 183 | 13.9 | 17.7 | 19.5 | 19.3 | 14.9 | 18.9 | 20.3 | 20.1 | 13.4 | 18.8 |
| 274 | 0.0 | 5.4 | 8.9 | 8.5 | 2.3 | 7.6 | 9.5 | 8.3 | 2.8 | 6.7 |

Table 24. SOIL WATER TENSIONS (CENTIBARS) AS QUARTERLY AVERAGES FOUND IN THE CENTER CAISSON AT ASHLAND FEEDERS, INC., FORT COLLINS, COLORADO

| Depth cm | 1971 | | 1972 | | | | 1973 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 15 | 33.8 | 19.0 | 23.0 | 24.0 | 29.6 | 41.5 | 38.2 | 37.6 | 36.1 | 47.8 |
| 61 | 23.8 | 16.3 | 20.0 | 22.0 | 25.2 | 29.4 | 29.2 | 28.7 | 27.5 | 36.2 |
| 91 | 21.5 | 14.5 | 18.1 | 19.8 | 21.8 | 24.3 | 24.2 | 24.2 | 22.8 | 29.0 |
| 183 | 15.8 | 16.4 | 20.8 | 22.0 | 19.3 | 21.2 | 24.2 | 24.2 | 18.2 | 21.7 |
| 274 | 10.7 | 14.4 | 16.9 | 17.3 | 12.4 | 15.9 | 17.6 | 17.5 | 11.4 | 16.1 |

Table 25. AVERAGE SOIL ATMOSPHERE COMPOSITION (PERCENT BY VOLUME) BENEATH A CROPPED FIELD AND FEEDLOT FOR TWO YEARS[a] AT ASHLIND FEEDERS, INC., FORT COLLINS, COLORADO

| Location | $O_2$ | $N_2$ | $CO_2$ | $CH_4$ | Total |
|---|---|---|---|---|---|
| Alfalfa | 18.6 | 80.7 | 0.6 | 0.0 | 99.9 |
| Bunk | 3.7 | 74.1 | 16.7 | 5.4 | 99.9 |
| Center | 5.8 | 82.4 | 11.7 | 0.0 | 99.9 |

[a] Means of 72 determinations over 4 depths.

The COD, $PO_4{}^3$, and pH data from the feedlot caisson showed no significant differences when compared with the control caisson in the alfalfa field. There were no marked differences in COD and $PO_4{}^3$ between the feedlot and control caissons.

The data that showed important, but not alarming, differences are in Table 18 for soil solutions. For the center caisson, the concentrations of $NO_3$-N were very high near the soil-manure interface, but these sharply decreased with depth. The groundwater beneath the lot had $NO_3$-N contents ranging from 7 to 11 ppm. Stewart et al. (25) found the average $NO_3$-N content to be 10 ppm in groundwater in northeastern Colorado. Headden (26) reported that samples of groundwater from the Fort Collins Agricultural Experiment Station ranged in $NO_3$-N concentration from 1 to 14 ppm.

One can explain the decline of $NO_3$-N with depth at the center caisson by considering the data in Tables 20-24 in conjunction with knowledge of the nitrifying bacteria in the soil. Note that in Tables 22, 23, and 24 the upper soil profile water tensions in the feedlot were fairly constant over the year. There were no pulses of water percolating in the feedlot as compared to the cropped alfalfa. The upper soil profile was quite dry (it was difficult to obtain soil solution samples with the ceramic cups). With a low soil water content, $NO_3$-N movement is principally by diffusion, a slow process in soil. Data in Table 21 showed that the peak in $NO_3$-N concentration was reached at a soil depth of 15.2 to 20.3 cm (6 to 8 in.). In fact, the nitrifying bacteria were inhibited near the soil-manure interface because of a combination of factors: low oxygen tension (see Table 25); high osmotic tension of the soil solution (see EC in Table 18 and low water content in Table 21); and toxicity of $NH_3$ due to the high pH. Consequently, both the formation and the movement of $NO_3$-N were severely limited. As the $NO_3$-N diffused away from the locus of formation, the low-oxygen tension environment favored denitrification, and little, if any, $NO_3$-N reached the water table. At the bunk site, nitrification was seemingly even more restricted, and the groundwater had more $NO_3$-N than the soil solutions from high in the profile.

The intact manure pack was surprisingly stable and longlived as a system to seal the soil so long as there was sufficient moisture and animal traffic. An intact column of manure pack and underlying soil has been observed for over 14 months in the laboratory. The only treatment has been the addition of 6.35 cm (2.5 in.) of water over the observation period and firming the surface (to simulate animal traffic). The manure pack continued to generate $CH_4$ and maintained a very low $O_2$ content of about 1 to 2% in the soil below.

## Composition and Amount of Percolate Using Vacuum Lysimeters

As anticipated at the beginning of the experiment, the Anderson (flat) site allowed the most significant percolation. Percolation rates ranged from 0.03 to 3.0 cm (.01 to 1.2 in.) per year over the study period. It should be noted that precipitation accounted for only 54% of the total water applied to the feedlot during the study period. The remainder, or nearly half, of the applied water was through animal excretion. The average annual stocking rate at this site was about 32.5 square meters (350 $ft^2$) per animal. With a higher stocking rate, the fraction of water applied as precipitation would be even less, because a large fraction of the water would be applied by animal excretion, and soil water patterns correspond well with animal traffic patterns. Areas near the feedbunk are continually moist. However, this surface moisture pattern does not indicate the pattern of deep percolation. Areas near the dry center of the lot had approximately 10 times the percolation of the wet area adjacent to the bunk, indicating that the maintenance of a wet manure pack effectively sealed the soil surface. During the study, the location of the feeding area was moved, resulting in drying of the manure pack over the lysimeter initially in the "bunk area." As a result of this drying, the percolation rate increased over a period of several months to a level comparable to that in the center of the lot. This observation supported a previous hypothesis that alternate wetting and drying resulting from partial-year operation contributes considerably to the potential pollution from a cattle feedlot.

During the study period, the total, weighted percolation averaged 0.5% of the total water applied to the surface, or about 0.25 cm (0.1 in.) per year.

At the Ashlind site, no measurable percolate was collected at the 75-cm (30-in.) depth of installation of the lysimeters. This conclusion is supported by results of neutron soil water analyses, of which Figure 14 is typical. Although the water content in the upper 75 cm of soil was increased significantly by the rainfall events, this water was subsequently lost to evaporation with no significant changes apparent in soil water content at deeper depths. During this same sequence of events, soil water measurements near the feedbunk showed virtually no change with time, further substantiating that the moist manure pack forms an effective seal. The chemical composition of leachates obtained from the lysimeters at the two locations is presented in Tables 26 and 27.

Values for all determinations were comparable to those to be shown later for the caissons for soil solutions. The lysimeters at the sloping Ashlind site never yielded sufficient leachate for determination of all the analyses, and by the end of 1971, the level, Anderson lysimeters also had no leachates.

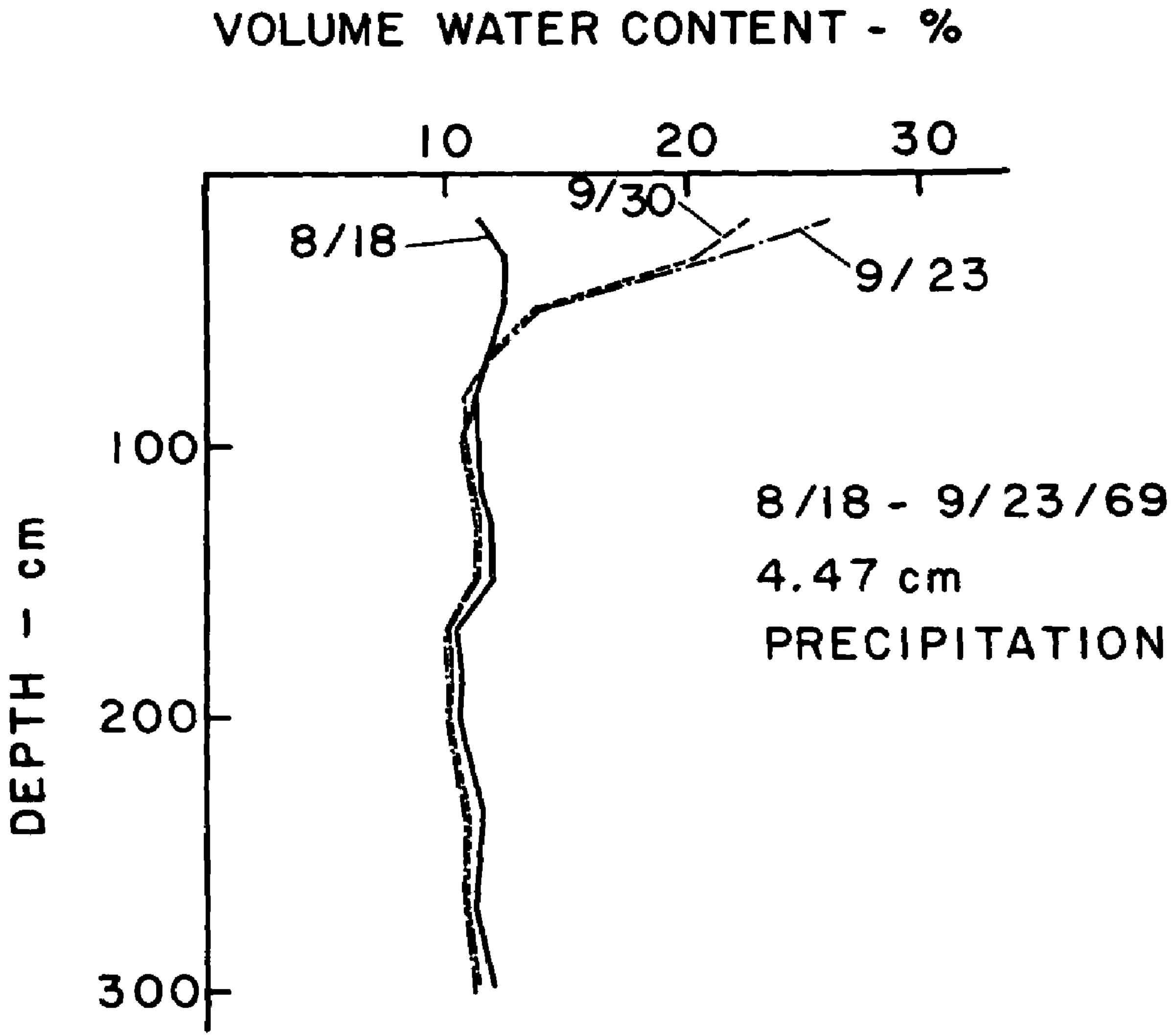

Figure 14. Water content profile near center of lot at sloping site.

Table 26. CHEMICAL COMPOSITION OF LEACHATES OBTAINED FROM VACUUM LYSIMETERS IN FEEDLOTS NEAR FORT COLLINS, COLORADO

| Measurement | Lysimeter Location | | | |
|---|---|---|---|---|
| | Anderson | | | Ashlind |
| | Bunk | Intermediate | Center | (Composite) |
| EC (mmhos/cm) at 25°C | 2.75 | 2.45 | 11.29 | 2.03 |
| pH | 7.68 | 7.71 | 6.26 | 7.63 |
| $NO_3$-N (ppm) | 1.83 | 4.11 | 767.33 | 4.46 |
| $NO_2$-N (ppm) | 0.250 | 0.232 | 0.081 | 0.025 |
| $NH_4$-N (ppm) | 0.93 | 0.11 | 5.38 | |
| N (total ppm) | 12.28 | 10.33 | 887.36 | |
| $PO_3^{3}$ | 0.245 | 0.220 | 0.170 | |
| P (total ppm) | 0.755 | 0.970 | 1.033 | |
| COD ($mgO_2$/1) | 358.2 | 750.0 | 3230.0 | 565.0 |

Table 27. CHANGES OF COMPOSITION OF LYSIMETER LEACHATES WITH TIME FROM CENTER OF ANDERSON FEEDLOT

| Date | Volume (ml) | EC,mmhos/cm at 25°C | pH | $NH_3N$ (ppm) |
|---|---|---|---|---|
| 6-25-69 | 260 | 6.72 | 7.30 | 280.0 |
| 8-6-69 | 570 | 18.20 | 7.20 | 1,550.0 |
| 9-3-69 | 47 | 19.40 | 4.40 | 1,630.0 |
| 11-6-69 | 340 | 23.00 | 4.10 | 1,144.0 |
| 4-14-71 | 50 | 0.20 | 7.00 | 0.0 |
| 10-8-71 | 13 | 0.22 | 7.60 | 0.0 |

The leachates from the center lysimeter at the level site showed a fluctuation in EC, pH, and $NO_3$-N over the period of operation. These changes are characteristic of a pulse of water and favorable nitrification conditions followed by restricted water movement and unfavorable nitrification (Table 27).

The small area enclosed by each vacuum lysimeter produced only small amounts of liquid, thus limiting the frequency of sampling as well as the number of determinations per sample. In general, the limited data showed little, if any, contaminants moving through the soil profile with an intact manure pack.

The lysimeter located in the center of the level feedlot showed a fluctuation in flow and composition of leachates suggestive of an initial failure to have a tight manure pack over the lysimeter. During the time of a poor pack there was considerable flow of water with high nitrate concentration. As soon as the manure pack was established, both flow and nitrate concentrations were markedly reduced.

### Experimental Feedlot and Lysimeters at Colorado State University Animal Science Facility

An experimental feedlot equipped with butyl, rubber-lined, soil pits, or lysimeters, was completed early in 1973. Data collection has just started for the composition of soil solutions and gases, and only tentative ideas can be drawn from the data (Tables 28 and 29).

The soil pits were filled with four combinations of soil as shown in Table 28, with two replications of each treatment across the center of the lot and at the bunk, for a total of 16 pits. The pits were fitted with ceramic vacuum extractors and gravity drainage to obtain soil solutions and gas diffusion tubes to sample soil gases. The analytical data for soil solutions draining by gravity are presented in Table 28. All the solutions obtained were low in $NO_3$-N and low in conductivity. There was no evidence of appreciable movement of $NO_3$-N in the artificial profiles.

In Table 29, the soil gas data show the effects on gas diffusion and component concentrations by the two different fill materials and their relative placement to the manure pack. For example, compare the quantity of $CH_4$ at 91 cm (36 in) in treatments 1 and 2. $CH_4$ was high in the sand and very low in clay loam. Comparison of the results at 91 cm (36 in) in treatments 3 and 4 indicates the restriction of $CH_4$ diffusion by clay loam and its relative ease in sand. Also, these data indirectly suggest the locus of $CH_4$ formation was principally in the manure pack.

Table 28. NITRATE AND NITRITE NITROGEN, ELECTRICAL CONDUCTIVITY AND pH OF SOIL SOLUTIONS OBTAINED FROM LYSIMETERS OF EXPERIMENTAL FEEDLOT AT FORT COLLINS, COLORADO, RIGDEN FARM, COLORADO STATE UNIVERSITY

| Treatment description | Measurement | | | |
|---|---|---|---|---|
| | $NO_3$-N, ppm | $NO_2$-N, ppb | EC mmhos/cm | pH |
| 1<br>Clay loam | 0.49 | 12.8 | 0.95 | 8.01 |
| 2<br>Sand | 0.96 | 62.7 | 1.10 | 7.69 |
| 3<br>Clay loam over sand | 2.11 | 228.7 | 0.82 | 7.95 |
| 4<br>Sand over clay loam | 0.30 | 12.3 | 0.81 | 8.01 |
| Bunk | 0.41 | 40.3 | 0.98 | 7.88 |
| Center | 1.25 | 90.5 | 0.89 | 7.91 |

Table 29. AVERAGE SOIL ATMOSPHERE COMPOSITION (PERCENT BY VOLUME) OF EXPERIMENTAL FEEDLOT SITE

| Sampling depth (cm) | Gas | Treatment Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | | 4 | |
| 45 | $O_2$ | Clay loam | 3.0 | Sand | 2.8 | Clay loam | 3.1 | Sand | 2.5 |
| | $N_2$ | | 87.2 | | 73.1 | | 86.0 | | 73.8 |
| | $CO_2$ | | 9.0 | | 15.9 | | 8.8 | | 13.2 |
| | $CH_4$ | | 0.8 | | 8.2 | | 2.0 | | 10.5 |
| | Total | | 100.0 | | 100.0 | | 99.9 | | 100.0 |
| 91 | $O_2$ | | 4.0 | | 3.8 | | 4.4 | | 2.4 |
| | $N_2$ | | 90.2 | | 72.9 | | 88.8 | | 85.8 |
| | $CO_2$ | | 5.6 | | 16.1 | | 6.5 | | 8.9 |
| | $CH_4$ | | 0.1 | | 7.2 | | 0.3 | | 2.9 |
| | Total | | 99.9 | | 100.0 | | 100.0 | | 100.0 |

NEBRASKA

## Physical Properties of Soil Sores

In a laboratory experiment with four undisturbed soil cores from a feedlot, average infiltration was 1.42 x $10^{-2}$ cm/day (.55 x $10^{-2}$ in/day) or about 5 cm/yr (2 in/yr). In one core, having the slowest infiltration, 1.5 cm (.6 in.) entered in 1 year and only 2 cm (.8 in.) in 540 days (27).

Physical characteristics were determined on six undisturbed feedlot cores from a Platte River valley site near Central City, Nebraska. The undisturbed cores encased in plastic (28) were segmented into sections 10 cm long (3.9 in.). The change in physical characteristics of soil caused by cattle in the feedlot was very pronounced and was limited to the top 15 to 20 cm (5.9 to 7.9 in.) of surface. Mixing of soil and organic matter occurred above and below an interface boundary. The most significant physical characteristic of soil profile in the beef cattle feedlot was the interface zone between the organic and inorganic layer. The interface zone is defined as the interface boundary between organic matter and mineral soil, including about 2 cm (.8 in.) above and 8 to 10 cm (3.2 to 3.9 in.) below the boundary. This layer influenced the movement of water, air, and nutrients in the soil profile and into the groundwater.

Bulk density of the soil was 1.70 to 1.80 g/$cm^3$ (.06 to .065 lb/cu. in.) in the interface section below the boundary. The bulk density of sections below the interface decreased to 1.4 g/$cm^3$ (.05 lb/cu. in.) which was comparable to that of cropland. Average bulk density of the organic surface section was about 1.0 g/$cm^3$ (.036 lb/cu. in.).

Organic carbon content was 9.3% in the manure surface layer and 2.4% in the interface layer. Ten centimeters (3.9 in.) below the interface layer, the organic carbon content of soil was 1.2%, which was about the same as in the soil of the surrounding cropland. The particle density of the manure surface layer was 2.35 g/$cm^3$ (.085 lb/cu in.) which was much lower than 2.68 g/$cm^3$ (.096 lb/cu. in.) for mineral soil. Air permeability of the feedlot surface and interface sections was 1.53 and 0.74 $microns^2$ respectively, and it increased to 12.8 $microns^2$ in the section below. Intrinsic water permeability for the same layers was 0.030 and 0.029 $microns^2$, and it increased to 0.51 $microns^2$ in the soil section below.

The high, organic-matter content in the surface and interface sections caused a very gradual decrease in water content with increasing suction up to 0.67 bar (9.7 lb/sq. in.). Large pores were absent and the small pores were responsible for low conductivity of water through the profile. Moisture release characteristics were different on disturbed samples of the same material. The change in pore volume and pore size distribution of disturbed material from the surface and interface sections caused a much greater change in water content over the same range of section than in the undisturbed sample. It is important when measuring physical characteristics of animal waste to use the correct sampling techniques and the right kind of sample.

Soil-core, bulk-density patterns did not show a trend attributable to feedlots. Some feedlot locations, compared with the adjacent cropland, showed a higher bulk density for the first 2.4 m (2.6 yd). Average bulk densities for the feedlot cores were 1.09 g/cm$^3$ (.04 lb/cu. in.) for the silt loam and 1.79 g/cm$^3$ (.065 lb/cu. in.) for the fine sandy loam soils. The manure in the mounds had a bulk density range of 0.65 to 0.97 g/cm$^3$ (.02 to .035 lb/cu. in.); however, bulk density generally increased with depth, indicating compaction, continued decomposition, and consolidation of the manure material (29, 30).

The water content in the feedlot soil profile was fairly uniform with profile depth. The feedlot surface tends to reduce water infiltration; however, results suggest a relatively stable soil-water condition with limited water entry into the profile and no well-defined wetting fronts. The profile beneath the mounds was generally drier than the surrounding feedlot profiles, which indicates a lower water intake.

## Chemical Properties of Soil Cores

### Sloping, Upland Feedlots

The sloping feedlots were found to accumulate nitrate in the upper 9.1 m (9.6 yd) of the soil profile (Figure 15). There is approximately 34.0 and 8.1 metric tons/ha. (15.2 and 7.4 tons/acre) more total N in the feedlot profile than in the cropland (corn) and abandoned feedlot profiles, respectively (Table 30), part of which can be converted to nitrate.

The nitrate remains in the upper 1.5 m (1.6 yd) of the profile, with most of the nitrate located on the lot surface (Figure 15). Water samples were obtained from 43 core sites and 9 (21%) were above 10 ppm $NO_3$-N. The mean $NO_3$-N concentration was 7.2 ppm. The highest concentrations above 10 ppm were generally flat, upland feedlot sites with a water table at less than 6.1 m (6.7 yd).

### Flat Feedlots

The flat feedlots were located on the Platte River floodplain on sandy-textured soil. The soil type resulted in 32.5 metric tons/ha. (14.5 ton/acre) total N, lower than observed under the other feedlot condition (Table 30).

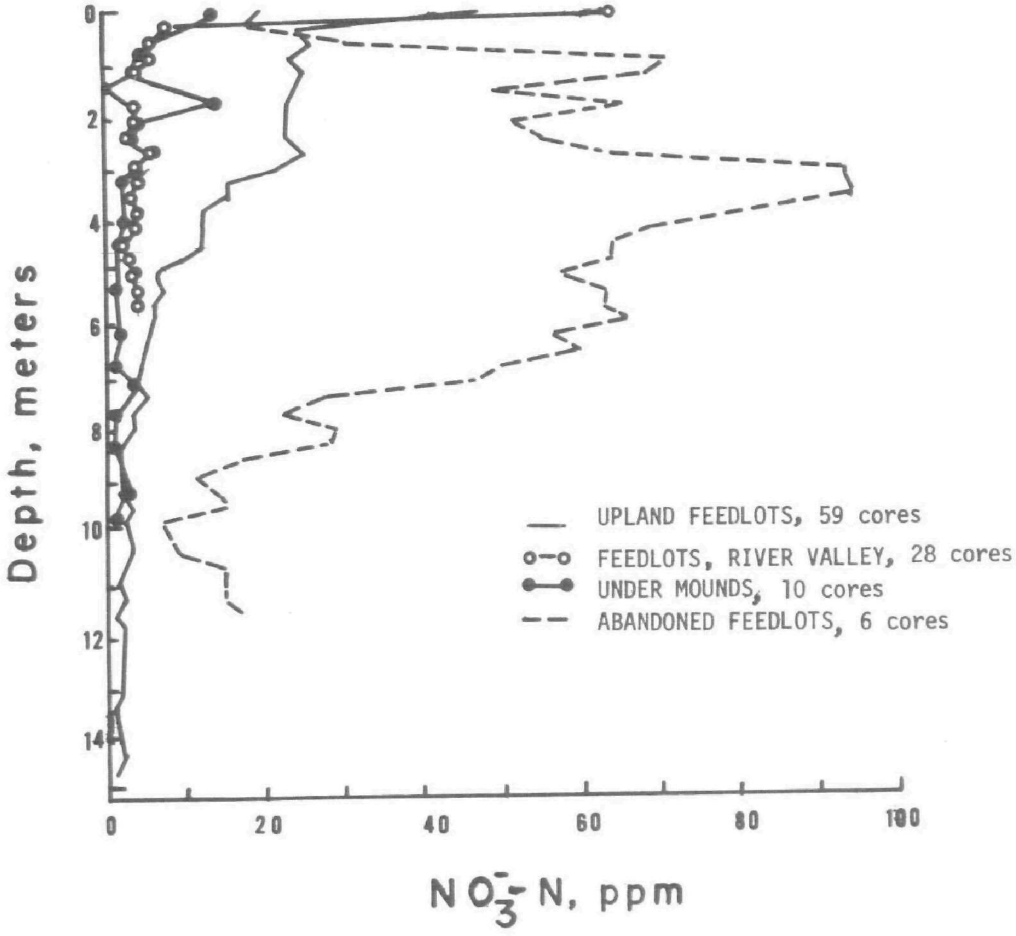

Figure 15. Average nitrate distribution values in the profiles of sloping-upland, flat manure mounds and abandoned feedlots

Table 30. AVERAGE QUANTITY OF NUTRIENTS IN A 9.1 m PROFILE UNDER THE DIFFERENT FEEDLOT AND CROP MANAGEMENT SYSTEMS INVESTIGATED. (kg/ha.)

| | | Nutrients accumulated to 9.1 | | |
|---|---|---|---|---|
| | No. of profiles | Total nitrogen | $NH_4^+$-N | $NO_3^-$-N |
| Sloping or upland feedlots | 59 | 76,100 | 3,740 | 1,840 |
| Profile under mounds | 10 | 54,000 | 6,840 | 502 |
| Flat (river basin) feedlots | 28 | 21,300 | 1,900 | 627 |
| Abandoned feedlots | 6 | 68,100 | 716 | 7,200 |
| Crop feedlot rotation | 5 | 47,900 | 347 | 2,090 |
| Corn | 10 | 42,000 | 319 | 1,100 |
| Alfalfa | 3 | 42,000 | 403 | 403 |
| Grassland | 8 | 18,000 | 224 | 224 |

The 630 kg/ha. (562 lb/acre) $NO_3$-N was one of the lowest quantities observed for feedlots, with only the mound having less $NO_3$-N (Table 30). Only 5% (1 of 20) of the water samples from the flat feedlots contained in excess of 10 ppm $NO_3$-N. The highest $NO_3$-N concentration detected in the water samples was 23 ppm, with a mean of only 4.2 ppm.

## Mounds

The mounds are one way in which a feeder can temporarily stockpile and store animal wastes deposited on the feedlot, and large quantities of nitrogen are stored in this manner. In the feedlots cored in this study, 394 and 170 metric tons/ha. (175 and 75.8 tons/acre) Kjeldahl N and $NH_4$-N were found in the average 4.0-m (4.4 yd) depth of mound.

In the soil profile under the mounds, only 53.8 metric tons/ha. (24 tons/acre) Kjeldahl N was found in 9.1 m (10 yd) profile. This quantity was 22.4 metric tons/ha. (10 tons/acre) less than the upland feedlots. The 9.1 m (10 yd) profiles under mounds contained the largest quantity of $NH_4$-N found in the cores, with 6.7 metric tons/ha. (3 tons/acre). None of the water-table samples contained in excess of 10 ppm $NO_3$-N.

## Abandoned Feedlots

The abandoned feedlots contained more $NO_3$-N in the profile than any other condition studied (Figure 14). In a 9.1 m (10 yd) profile, there was 7.2 metric tons/ha. (3.2 ton/acre) of $NO_3$-N. This was almost 3.5 times the quantity of $NO_3$-N accumulated under any other feedlot management system (Table 30).

Abandoned feedlot management appears to be an important consideration in the accumulation of $NO_3$-N in a soil profile. One abandoned site accumulated 19.4 metric tons/ha. (8.7 tons/acre) of $NO_3$-N in the 7.6-m (8.3 yd) profile. Feedlots which were abandoned and then cropped showed some decrease in $NO_3$-N levels throughout the profile; however, variability within a single lot is too great to draw conclusions.

Two of three (67%) of the water samples had $NO_3$-N concentration greater than 10 ppm. The average $NO_3$-N concentration for the water samples was 40.6 ppm, with a high of 77.2 and a low of 0.6 ppm.

## Feedlot-Cropland

Five sites cored were used for cattle feeding. The feedlot-cropland rotation has $NO_3$-N buildup characteristics intermediate between these kinds of land use. There are large quantities of $NO_3$-N in the first 2.4 m (2.6 yd) of the soil profile and a large percentage of the cores to 9.4 m (10.3 yd) have more than 10 ppm $NO_3$-N.

The 2.1 metric tons/ha. (.94 tons/acre) $NO_3$-N found in a 7.6-m (8.3 yd) profile is more than in the feedlot but less than the abandoned feedlots. The $NH_4$-N levels were low compared with feedlots and comparable to the cropland $NH_4$-N levels. There was an increase in Kjeldahl N of 5.9 metric tons/ha. (2.6 tons/acre) over the corn and alfalfa but 28.2 metric tons/ha. (12.6 tons/acre) less than the feedlot. The nitrogen data indicate that there is an increase in the $NO_3$-N levels in the soil, which has not been utilized by the crops during the summer. The maximum, mean, and low $NO_3$-N concentrations in groundwater samples were 19.1, 13.4, and 9.7 ppm, respectively. Two of three samples (67%) contained $NO_3$-N in excess of 10 ppm.

# SECTION IX

# INVESTIGATIONS ON METHODS OF EXTRACTION OF NITRATE FROM THE SOIL PROFILES OF ABANDONED FEEDLOTS

## NEBRASKA

### Introduction

When feedlots are abandoned, large quantities of nitrogen remain that are readily convertible to nitrate. Even if the manure layer is removed, quantities of nitrogen in the form of ammonium and organic nitrogen remain in the upper portion of the feedlot soil profile. As oxygen becomes available to the soil profile, these compounds can be converted microbially to nitrate.

Recent soil-coring studies by Mielke and Ellis (31) have shown nitrate concentrations beneath abandoned feedlots may become quite high. In the abandoned feedlots sampled, the average quantity of nitrate-nitrogen in the 9.1-m (10 yd) profile was 7,202 kg/ha. (6424 lb/acre). These nitrates at the deeper depths have moved below the plant root zone and may eventually leach to the water table. Water samples obtained from the groundwater below the abandoned feedlots (32) ranged from 0.6 to 77.3 ppm $NO_3$-N (average 40.5 ppm).

Obviously, there is a need to limit or stop the movement of nitrate from abandoned feedlots. This task might be accomplished by establishing a high-nitrate-requiring and/or deep-rooted crop on the feedlot area when it is abandoned.

### Objectives and Methods

The purpose of this study was to establish crops which will extract the nitrates from the soil profile on the abandoned feedlot. Because salt concentrations are high at the feedlot surface, provisions were made by surface material removal and crop selection.

In the spring of 1972, a portion of a feedlot was abandoned and used as the experimental site. A total of 12 plots, 4.2 x 6.1 m (5 x 6.7 yd) each, with 0.6 m (.66 yd) wide borders, was established. The randomized plot diagram and treatments are shown in Figure 16. Fifteen centimeters (5.9 in.) of material were removed from plots 2, 4, and 6 and replaced with topsoil from adjacent farmland. The topsoil-addition treatment was included to alleviate any possible salt problems. The plots were seeded with alfalfa and corn in May, 1972. These crops have moderate-to-good salt tolerance and will remove

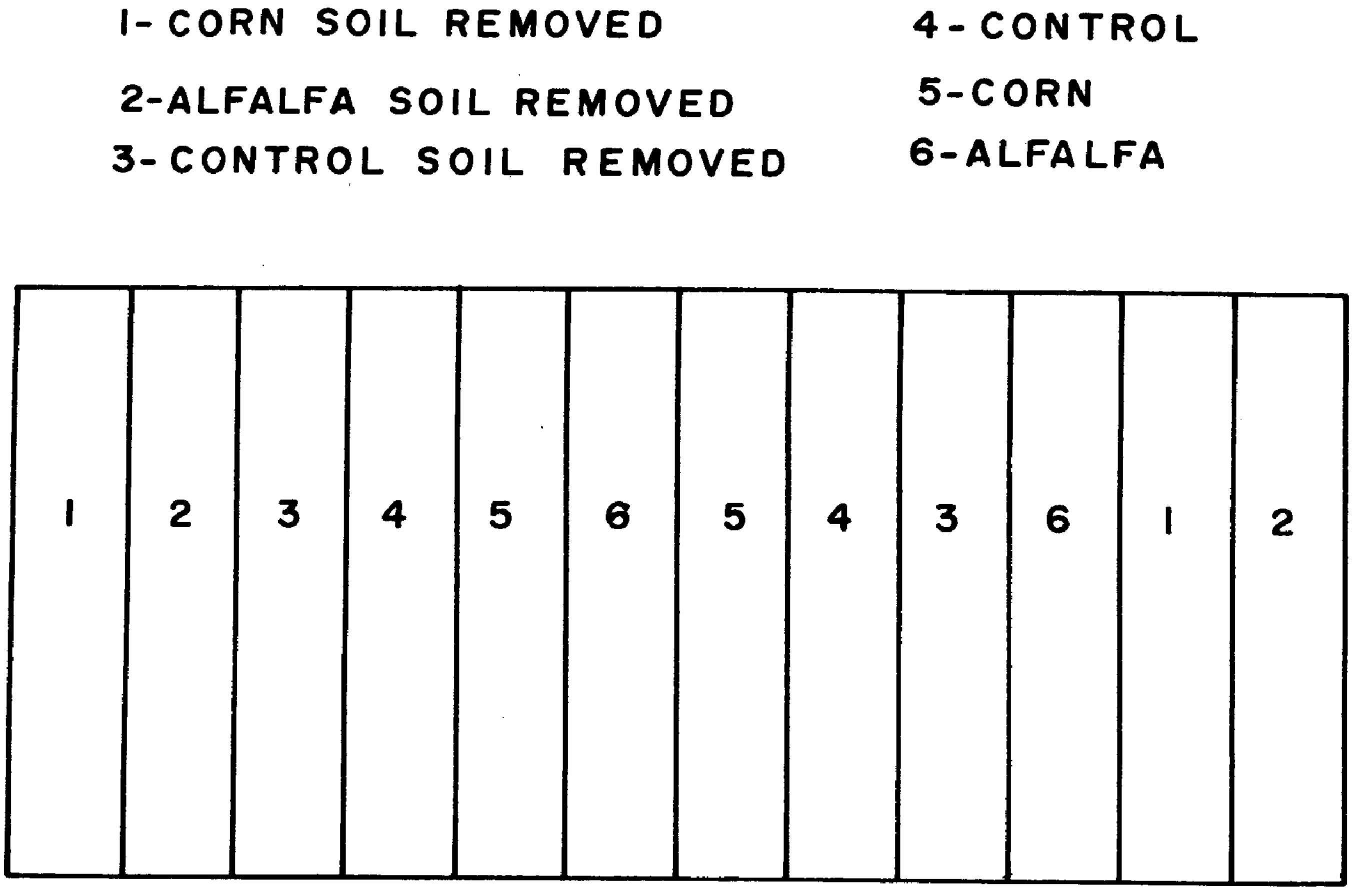

Figure 16. Experimental plot layout on abandoned feedlot.

nitrates from the soil profile. Duplicate soil cores were taken to 3.0 m (3.3 yd) from each plot prior to planting and after harvest in the fall to assess the nutrient status of the soil profile. These cores were analyzed for ammonia, nitrate, nitrite, phosphorus, and cations at 0.3 m (.33 yd) increments of depth. Plant samples and yields were taken to determine the amount of nitrogen removed from the soil profile.

## Results

Crop yields and nitrogen uptake for the 1972 and 1973 cropping seasons are shown in Table 31. The data show that the nitrogen uptake of the corn in 1972 was significantly higher than that of the alfalfa; however, after the alfalfa becomes established, its nitrogen uptake is greater than that of the corn. Nitrate analysis of the plant material showed that the nitrate levels of the corn were 2,230 and 7,423 ppm for $NO_3$-N in the stalk.

Table 31. YIELDS AND NITROGEN UPTAKE OF THE ALFALFA AND CORN ON AN ABANDONED FEEDLOT

| Treatment | Forage yield (metric tons/ha.) | | Grain yield (hl/ha.) | | Nitrogen uptake (kg/ha.) | |
|---|---|---|---|---|---|---|
| | 1972 | 1973 | 1972 | 1973 | 1972 | 1973 |
| Alfalfa | | | | | | |
| Feedlot surface | 5.15[a] | 16.76[b] | | | 110 | 441 |
| Soil removed | 3.83 | 13.37 | | | 84 | 348 |
| Corn Forage | | | | | | |
| Feedlot surface | 7.53 | 11.31 | | | 98 | 150 |
| Soil removed | 9.12 | 6.94 | | | 108 | 93 |
| Corn Grain | | | | | | |
| Feedlot surface | | | 65.8 | 96.7 | 72 | 128 |
| Soil removed | | | 73.0 | 71.9 | 78 | 95 |

[a] Total of 2 alfalfa cuttings in 1972 (year established).

[b] Total of 4 alfalfa cuttings in 1973.

## SECTION X

## AIRBORNE POLLUTANTS

### INTRODUCTION

Hutchinson and Viets (33) showed that volatilization of $NH_3$ from beef cattle feedlots contributed significant quantities of $NH_3$ to the atmosphere and potentially to surface waters. Their data indicated a lake in the vicinity of a large feedlot absorbed enough $NH_3$ per year to raise its N content 0.6 ppm.

While $NH_3$ would seem to be the principal form of N volatilized from a feedlot, there is a possibility other forms of N, such as volatile amines and heterocyclic compounds, also could contribute significant quantities of N to the air and, subsequently, to surface waters. These compounds are not only odorous but also offer a metabolizable substrate readily absorbed by water. Laboratory and confinement-unit studies indicate volatile N-containing compounds emanate from, or are contained in, manure. Merkel, Hazen, and Miner (34) found amines in the atmosphere of a swine confinement unit. Aliphatic amines were detected in incubated chicken manure (35). Burnett (36) showed indole and skatole, among other components, contributed to the odor of chicken manure. Deibel (37) also found indole to be an odor component of chicken manure. Since volatile N-containing compounds are found in chicken and swine manure, some or all of these compounds probably volatilize from cattle manure, along with $NH_3$, and contribute to odor.

### NEBRASKA

#### Volatilization of Ammonia and Basic N Compounds

Ammonia and basic compounds, such as amine, were trapped in acid. The traps were constructed as described by Hutchinson and Viets (33) and were placed around a small feedlot at the Central City site, in and adjacent to a cattle pasture, and on cropland at the Treynor, Iowa, site. The traps, fabricated of wire mesh with a conical metal roof and a plywood floor, were placed 1.5 m (1.6 yd) above the ground on posts. Each trap contained a 750-ml (45.8 cu. in.) plastic dish filled with 0.01 $\underline{N}$ $H_2SO_4$. The trapping solution usually was changed every 1 to 3 weeks during the year, depending on the evaporation rate.

Two traps containing 0.02 $\underline{N}$ $Na_2CO_3$ were included at the Central City site on the east and west ends of the feedlot fence. These solutions were tested for total N. Because of the alkalinity of this solution, any N present would be due to dust contamination. This measurement determines whether the N present in the acid-trap solution reflects absorption of volatile N compounds and/or dust contamination.

The acid-trap solutions were assayed for distillable N by steam distillation with MgO into boric acid and titrated with dilute $H_2SO_4$ (38). Total N was measured in the sample by $H_2SO_4$ digestion and steam distillation with NaOH into boric acid and titration (39). Results showed amines and basic N-containing compounds were probably absorbed in the trapping solution along with $NH_3$. Because some of these N-containing compounds, probably short-chain amines, would distill and titrate as $NH_3$, the steam distillation value obtained here is called distillable N rather than $NH_3$-N. The distillable-N value is subtracted from the total N value and called nondistillable N.

The method described by Ekladius and King (40) was used to test for aliphatic amines.

Average values for distillable N absorbed by the three traps around the feedlot and by two traps in the surrounding cropland are plotted in Figure 17.

Distillable-N evolution from the feedlot was variable. No livestock were in the feedlot until the first part of October. Periods of appreciable precipitation during the fall sampling period were followed by an increase in distillable-N evolution. The high distillable N the first part of August coincided with rain and manure-mounding. This peak was much higher than later peaks preceded by precipitation, so it was assumed the surface disturbance caused by mounding increased the quantities of distillable N being released. Mounding is practiced in this area as a method of on-site manure disposal and to provide a dry area for the animals. Distillable-N evolution increased greatly in October when animals were placed in the feedlot and rain wet the feedlot (Figure 17). As cold weather set in and precipitation decreased, distillable-N evolution decreased. The spring was extremely dry and distillable-N evolution did not generally increase with warming weather until late March. Distillable-N evolution increased in late March and early April even though the cattle were taken from the lot in April and precipitation was limited. The increase in distillable N trapped at the feedlot and controls during this period coincided with application of anhydrous $NH_3$ to adjacent cornfields. However, other factors probably enter into the distillable-N increase in the spring.

Throughout the year, distillable N trapped at the feedlot site was much greater than that trapped in the cropland. The yearly average values were 148 kg/ha. (132 lb/acre) per year for the feedlot and 16 kg/ha. (14 lb/acre) per year for the cropland, a significant difference at the 5% level as determined with the F test.

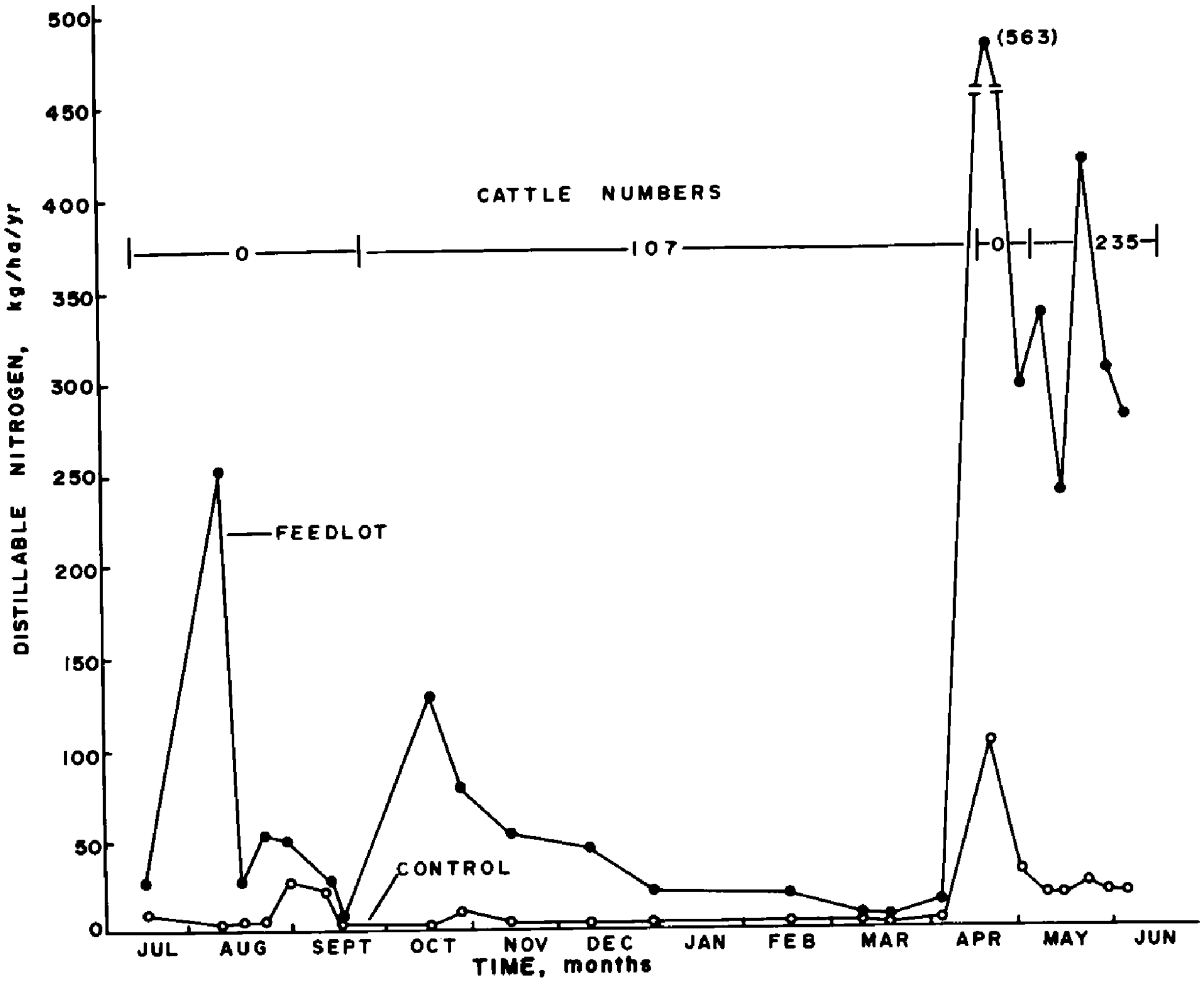

Figure 17. Distillable N absorption from the air around a small feedlot and adjacent cropland at Central City, Nebraska.

Figure 18 shows nondistillable N from the traps around the feedlot and the cropland. Obviously, significant quantities of N other than $NH_3$-N came from the feedlot. For the short period, the feedlot averaged 21 kg/ha. (18.7 lb/acre)/yr nondistillable N, while the cropland averaged 3.3 kg/ha. (2.9 lb/acre)/yr which was significantly different at the 5% level. For the same period, distillable-N evolution was 218 and 23.6 kg/ha. (194 and 21 lb/acre)/yr for the feedlot and cropland, respectively. Total-N values from the traps filled with $Na_2CO_3$ during the same period were 1 kg/ha. (.89 lb/acre)/yr or less, so the values obtained from the acid traps should represent basic volatile-N compounds and not N from dust contamination (7).

The results obtained from the cattle pasture and cropland at Treynor, Iowa, (Site 2) are shown in Figure 19. The values obtained from July through November were tested with the F test, and the pasture area was significantly different from the cropland at the 5% level. To the middle of November, distillable N trapped around the pasture was significantly greater than that trapped from cropland. In the latter part of November, the cattle were taken off the pasture and put on the cropland corn stubble. Consequently, from late November to late February, greater amounts of distillable N were trapped from the cropland than from the pasture. For the year, distillable-N evolution averaged 15 kg/ha. (13.4 lb/acre)/yr from the pasture and 11 kg/ha. (9.8 lb/acre)/yr from the cropland. The distillable-N values in this case probably represent $NH_3$ almost exclusively. For the pasture, the value for nondistillable N was 0.45 kg/ha. (.4 lb/acre)/yr and for the cropland was 0.30 kg/ha. (.27 lb/acre)/yr (7).

## COLORADO

### Significance of Ammonia to Plants

Monitoring the disappearance of $NH_3$ from an airstream flowing through a small growth chamber containing a single corn, soybean, cotton, or sunflower seedling about 15 to 25 cm (5.9 to 9.9 in.) tall indicated that plant leaves absorb significant quantities of $NH_3$ from the air, even at naturally-occurring, low-atmospheric, $NH_3$ concentrations.

Measured $NH_3$ absorption rates showed large diurnal fluctuations and varied somewhat among species, but differed little with the nitrogen fertility level of plants within a species. The data indicate that a field crop growing in air containing $NH_3$ at normal atmospheric concentrations might satisfy as much as 10 to 20 percent of its total N requirement by direct absorption of $NH_3$ from the air. In areas where the atmosphere has been enriched with $NH_3$ volatilized from cattle feedlot surfaces, this fraction might be even higher.

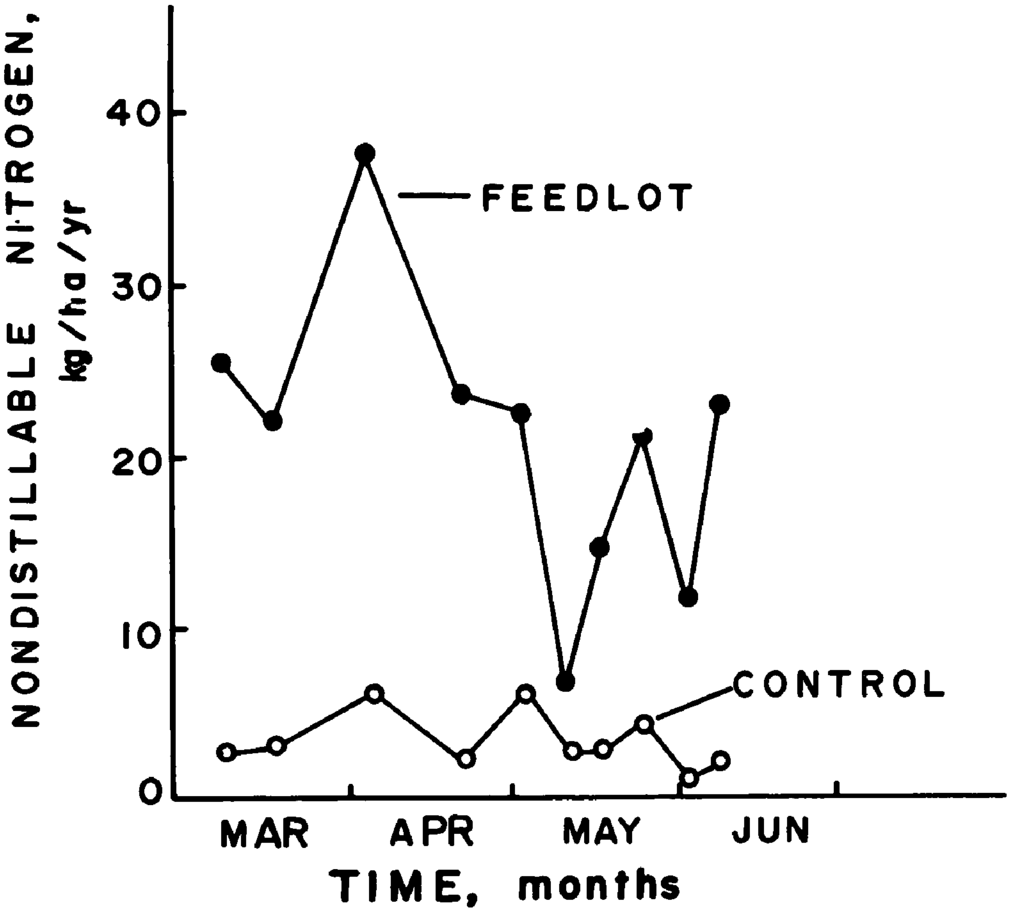

Figure 18. Nondistillable N absorbed by the trapping solution at Central City, Nebraska.

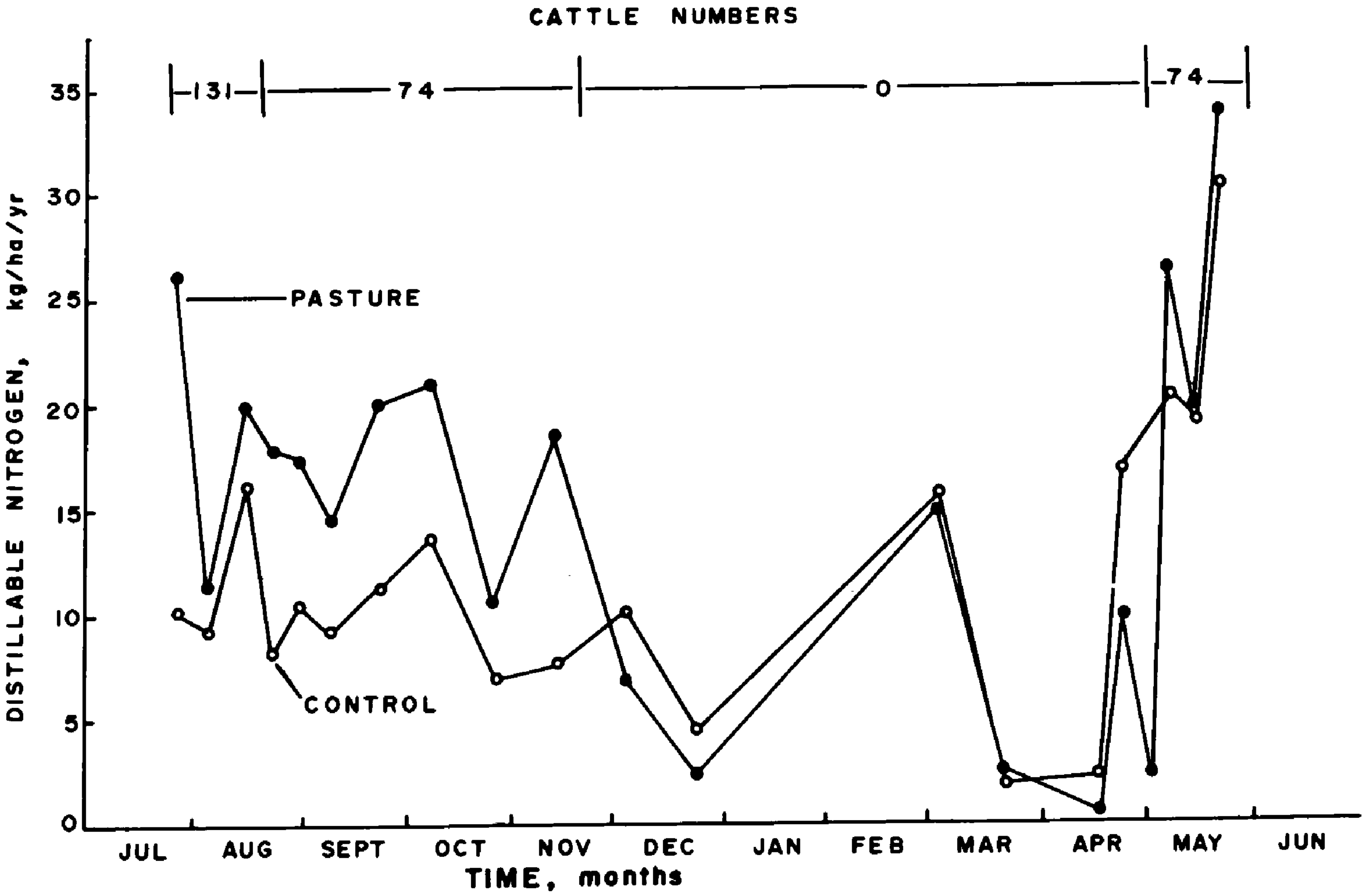

Figure 19. Distillable N volatilized from pastured cattle and cropland near Treynor, Iowa.

Foliar $CO_2$ and $NH_3$ uptake rates measured in a typical 24-hour experiment are shown in Figure 20. Details of the experimental procedures used in the experiments are described by Hutchinson (41). The $NH_3$ absorption rate shown in Figure 20 was relatively constant during the first day, but dropped sharply at the beginning of the dark period, apparently reflecting the closing of the stomata. It is important to realize that, since the mass flow of $NH_3$ into the plant chamber remained constant, the lower absorption rate at night occurred in the presence of an $NH_3$ concentration about three times greater than the day concentration; thus the difference in day and night uptake rates is even more pronounced than is first apparent in the graph. Immediately after the lights were turned on the following morning, the $NH_3$ absorption rate climbed rapidly and after about two hours reached a plateau slightly higher than that which prevailed the preceding day. The higher uptake rate on the second day is at least partially attributable to an overnight increase in the leaf surface area. The uptake of $CO_2$ followed a pattern similar to that of $NH_3$ except that the net uptake was, of course, negative during the dark period owing to the respiratory release of the gas.

The total amount of $NH_3$ absorbed by the soybean during the experiment, about 70 μg, was nearly enough to saturate the amount of water contained in the plant, if its pH were 6.50. Therefore, the absence of any hint of $NH_3$ saturation in Figure 20, along with the strong dependence of the uptake rate on stomatal opening, lends support to our contention that the absorbed $NH_3$ was metabolized rather than simply adsorbed onto exterior leaf surfaces or passively dissolved in the water bathing leaf mesophyll cells. Additional evidence is provided by Porter _et al._ (42) who found $^{15}N$-enriched amides, amino acids, and proteins in plants previously exposed to labelled gaseous $NH_3$.

Subsequent experiments were designed to determine whether foliar uptake of gaseous $NH_3$ was limited primarily by the diffusion rate of $NH_3$ through air or by some biochemical or biophysical bottleneck deeper inside plant leaves. Rates of foliar uptake of gaseous $NH_3$, net photosynthetic rates, and transpiration rates of corn and soybean seedlings were computed from the changes in $NH_3$, $CO_2$, and $H_2O$ vapor concentrations of a gas mixture flowing through a plant growth chamber in which a single corn or soybean seedling was growing. Results of all the experiments are summarized in Figure 21 where the $NH_3$ uptake rate measured under each set of experimental conditions is plotted against the diffusion-limited uptake rate predicted by the following equation for the same set of conditions: $NH_3$ uptake equals $C_a/r_a + r_s$, where $C_a$ is the $NH_3$ concentration of bulk air outside the plant leaf, $r_a$ is the diffusive resistance to $NH_3$ transport across the boundary layer surrounding the leaf, and $r_s$ is the resistance to

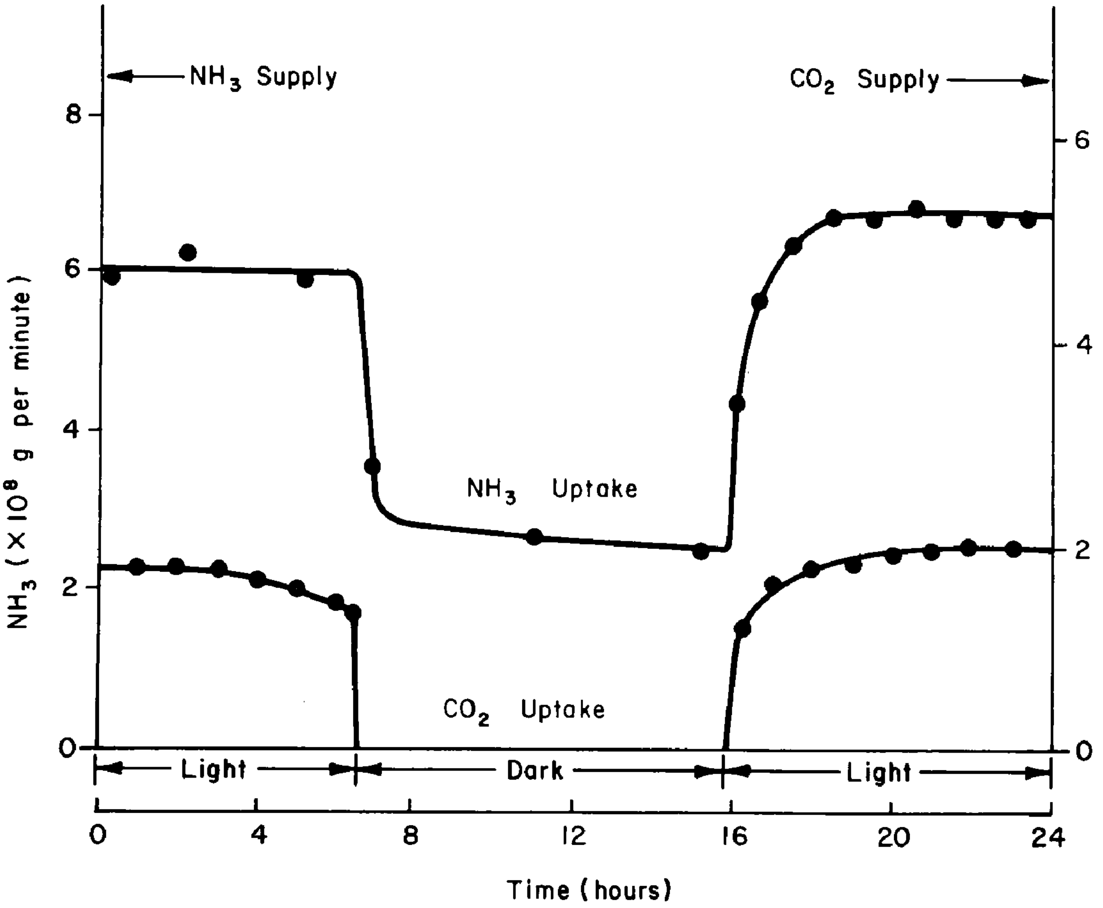

Figure 20. Foliar $CO_2$ and $NH_3$ uptake rates of soybean (final leaf surface area, 89 cm$^2$).

diffusion of $NH_3$ through leaf stomata and substomatal cavities to the surface of a leaf mesophyll cell wall. The equation was derived from the general gas diffusion equation based on the resistance model first advanced by Gasstra (43) by applying a series of arguments leading to the conclusion that both the leaf mesophyll resistance to $NH_3$ diffusion and the $NH_3$ concentration in plant cell fluids are negligible (41). The total of the two resistance terms in the above equation was estimated for each set of experimental conditions from transpiration, $H_2O$ vapor concentration, and temperature data by assuming that air adjacent to mesophyll cell wall surfaces is saturated with respect to $H_2O$ vapor, and that identical geometrical limitations are imposed upon the diffusion both $NH_3$ and $H_2O$ vapor as they move, albeit in opposite directions, between wet mesophyll cell wall surfaces and bulk air outside the plant leaves.

Figure 21 includes data for two different crop species and for experiments conducted under a wide range of environmental conditions. The ranges of environmental variables represented by data points in the graph were: atmospheric $NH_3$ concentration, 150 to 1530 $\mu g\ m^{-3}$; atmospheric $CO_2$ concentration, 50 to 540 ppm (v/v); air temperature, 18.7 to 32.9° C; and incident light energy, 0.3 to 0.7 cal $cm^{-2}\ min.^{-1}$ All the data points fall very close to the line rising diagonally from the origin with slope equal to one, indicating that the $NH_3$ uptake rates measured experimentally were nearly identical to those theoretically expected if the uptake were diffusion-limited. On the average, predicted $NH_3$ uptake rates were only about two percent lower than measured ones. The conclusion drawn from Figure 21 is that the observed differences among $NH_3$ uptake rates induced by modifying the atmospheric $CO_2$ or $NH_3$ concentration, air temperature, or light intensity were manifestations only of the effect of these variables on the effective cross-sectional area available for diffusion represented by the sum of the areas of stomatal aperatures. Apparently, then, the wet surfaces of corn and soybean mesophyll cell walls behaved as infinite sinks for atmospheric $NH_3$ over the range of concentrations studies, and foliar $NH_3$ uptake was limited only by the time required for gaseous $NH_3$ molecules to diffuse from external air through the stomata to a wet, cell wall surface.

The importance of atmospheric $NH_3$ as an agent for the transport and redistribution of N both within and among ecosystems has been vastly underestimated. Cattle feedlots are apparently one of the major sources of $NH_3$ in the atmosphere. Research has shown that a significant amount of the $NH_3$ volatilized from the surface of cattle feedlots is absorbed by soil and water surfaces in the vicinity of the feedlots. The data invalidate the concept that only runoff and deep percolation from cattle feedlots require control to prevent N enrichment of the surrounding environment. Although control of runoff

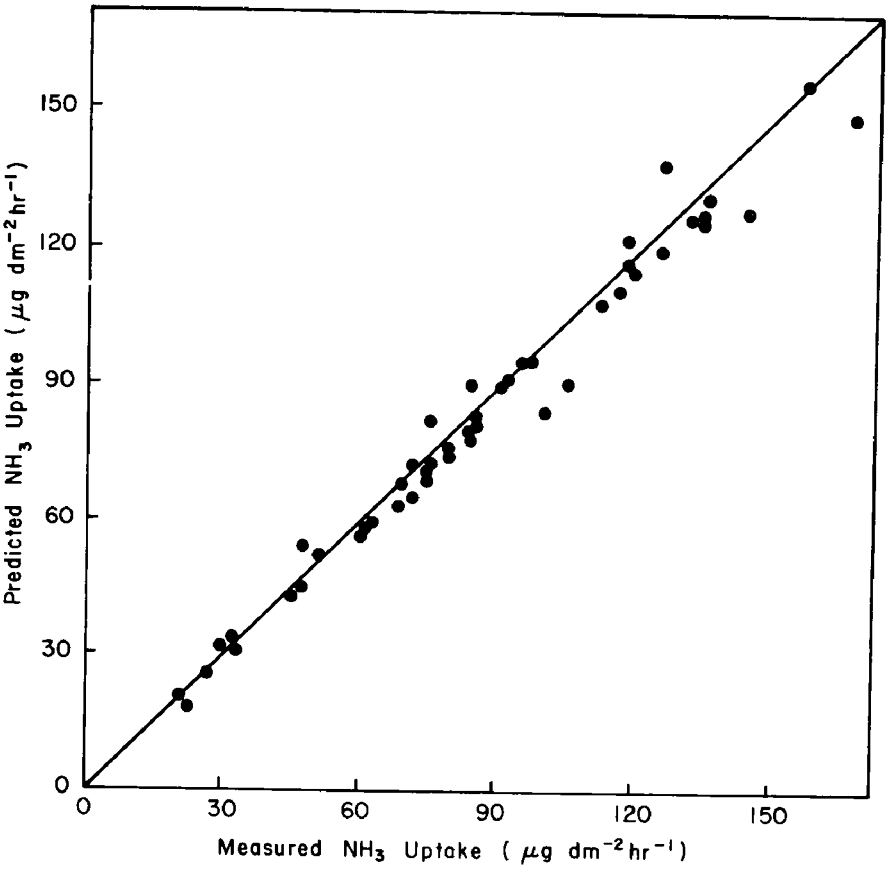

Figure 21. $NH_3$ uptake rates predicted by equation $C_a/r_a + r_s$ vs. $NH_3$ uptake rates measured experimentally. The diagonal line through the graph represents all points with equal coordinates.

into streams to prevent pollution by sediment, phosphorus, and organic wastes justifies adequate and often expensive design of feedlot installations, N pollution may still occur.

Calculations based on the data in Figure 20 indicate that annual $NH_3$ absorption by plant canopies growing in air containing $NH_3$ at normal atmospheric concentrations could be about 20 kg per hectare. This rate of $NH_3$ supply is large enough to contribute significantly to the N budget of a growing plant community and could exert a prodigious influence on the long-term behavior of an ecosystem. Near cattle feedlots where the atmosphere is enriched with feedlot volatiles, foliar $NH_3$ absorption is probably even higher. Our data, together with data on the absorption of atmospheric $SO_2$ (44) and $O_3$ (45) by plant leaves, also suggest an important role for green vegetation in the decontamination of the earth's atmosphere.

## Identification of Aliphatic Amines from Cattle Feedlot Volatiles and the Effect of these Compounds on *Chlorella Ellipsoidea*

Studies were initiated to determine if appreciable quantities of volatile N-materials other than ammonia are evolved from cattle feedyards, to illucidate their chemical composition to determine their effect on aquatic organisms.

Seven aliphatic amines have been identified and the presence of other higher molecular weight N-compounds are suspected. The materials identified and their concentrations relative to ammonia are shown in Table 32 (46). These seven compounds are estimated to comprise about five percent of the nitrogen volatilized from a cattle feedyard.

Efforts to separate these nitrogen volatiles from ammonia and to identify them led to the development of a new gas chromatographic (GC) technique for the separation and characterization of aliphatic amines and the revision of a method in which derivatives of aqueous solutions of amines could be prepared for confirmatory analysis. The new GC system (47) involved injection of aqueous samples of amine hydrogen sulfate salts onto an Ascarite precolumn in a GC inlet chamber and subsequent separation of the different amines on specific types of GC columns. This method was also adapted to the analysis of aliphatic N-nitrosamines (48). The new amine derivative procedure involved the preparation of stable pentafluorobenzamide compounds from pentafluorobenzoyl chloride and aliphatic amines in aqueous solution (46).

As appreciable amounts of nonammonia volatile nitrogen were shown to evolve from cattle feedyards, work was initiated to determine if the aliphatic amines were biologically active in the surface waters which can collect them. *Chlorella ellipsoidea* was selected as the test

Table 32. ALIPHATIC AMINES IDENTIFIED AS FEEDLOT VOLATILES AND THEIR CONCENTRATIONS RELATIVE TO AMMONIA

| Amine | Concentration as % of Ammonia |
|---|---|
| Methyl amine | 1.0 |
| Dimethyl amine | 0.5 |
| Ethyl amine | 2.0 |
| *n*-propyl amine | 0.5 |
| *iso*-propyl amine | 1.0 |
| *n*-butyl amine | 0.1 |
| *n*-amyl amine | 0.1 |

organism. Studies were initiated to determine if the amines affect the alga in pure culture. The initial studies showed that the amines affect algal population growth. A 50 percent reduction in algal population growth, $P_{1/2}$, was detected at amine concentrations ranging from 1.2 to 143 ppm amine-N (Table 33). Subtoxic amine concentrations stimulated algal growth (Figure 22). Primary amines were more inhibitory than *iso*-, *sec*-, and dialkyl amines (49). The source of inorganic N, ammonium or nitrate, had little effect on $P_{1/2}$ values of the normal primary amines and dimethyl amine. However, initial N source did affect the toxicity of the branched primary amines and diethyl amine. Apparently the configuration of the amine is important in its inhibition of the alga's metabolism. It was also found that the alga could not utilize amine-N for growth, with or without an added N source.

To attempt to illucidate the mechanism(s) by which amines affect *C. ellipsoidea* metabolism the effect of methyl amine on the alga's N metabolism, photosynthesis, and respiration was investigated. Methyl amine accelerated ammonium assimilation (Figure 23) but did not affect short-term nitrate uptake (apparently nitrate reduction is the rate-limiting step in nitrate assimilation). A Lineweaver-Burke treatment of ammonium uptake data (Figure 23) shows that methyl amine was not competing with ammonium for the site of enzymatic ammonium assimilation.

Table 33. STATISTICS RELATING ALGAL POPULATION TO AMINE CONCENTRATION

| Amine | Nitrogen Source[a] | Regression Equation | Correlation Coefficient | $P_{\frac{1}{2}}$[b] |
|---|---|---|---|---|
| | | | | ppm |
| Methyl | $NO_3^-$ | $\log \hat{y} = 3.42-0.256x$ | 0.997 | 1.2 |
| | $NH_4^+$ | $\log \hat{y} = 3.39-0.072x$ | 0.881 | 4.2 |
| Dimethyl | $NO_3^-$ | $\log \hat{y} = 3.49-0.01x$ | 0.995 | 31.7 |
| | $NH_4^+$ | $\log \hat{y} = 3.27-0.008x$ | 0.988 | 36.3 |
| Ethyl | $NO_3^-$ | $\log \hat{y} = 3.30-0.006x$ | 0.985 | 48.6 |
| | $NH_4^+$ | $\log \hat{y} = 3.49-0.007x$ | 0.954 | 41.2 |
| Diethyl | $NO_3^-$ | $\log \hat{y} = 3.49-0.003x$ | 0.972 | 120.4 |
| | $NH_4^+$ | $\log \hat{y} = 3.27-0.008x$ | 0.989 | 36.7 |
| *n*-Propyl | $NO_3^-$ | $\log \hat{y} = 3.54-0.005x$ | 0.988 | 60.2 |
| | $NH_4^+$ | $\log \hat{y} = 3.57-0.005x$ | 0.966 | 59.1 |
| *iso*-Propyl | $NO_3^-$ | $\log \hat{y} = 3.48-0.002x$ | 0.970 | 142.9 |
| | $NH_4^+$ | $\log \hat{y} = 3.50-0.014x$ | 0.971 | 187.6 |
| *n*-Butyl | $NO_3^-$ | $\log \hat{y} = 3.45-0.005x$ | 0.888 | 59.04 |
| | $NH_4^+$ | $\log \hat{y} = 3.42-0.011x$ | 0.971 | 27.36 |
| *sec*-Butyl | $NO_3^-$ | $\log \hat{y} = 3.47-0.003x$ | 0.945 | 120.4 |
| | $NH_4^+$ | $\log \hat{y} = 3.50-0.004x$ | 0.939 | 77.7 |

[a] Cells were cultured in a nutrient solution containing either nitrate or ammonium.

[b] Concentration of amine which reduces the alga population growth by one half.

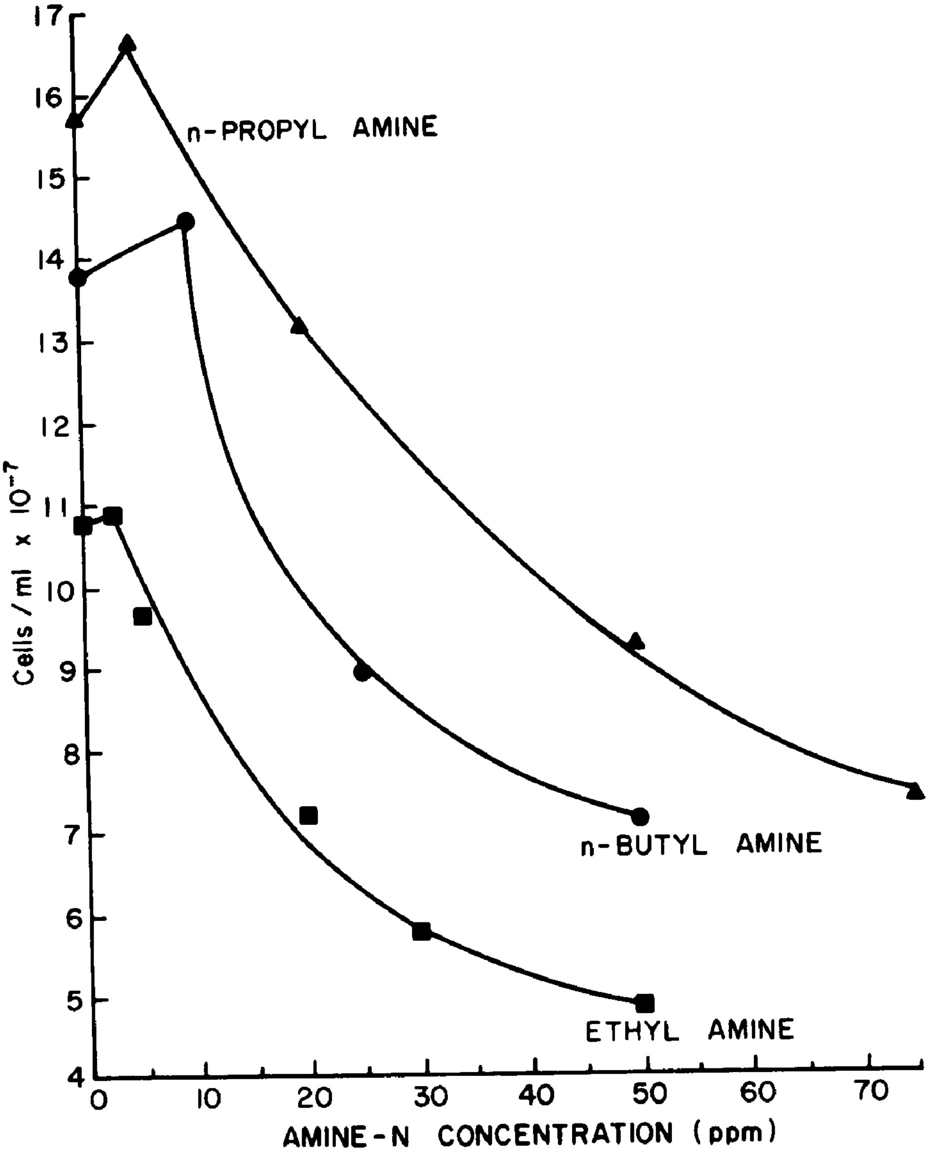

Figure 22. Effect of amine concentration on *C. ellipsoidea* population growth.

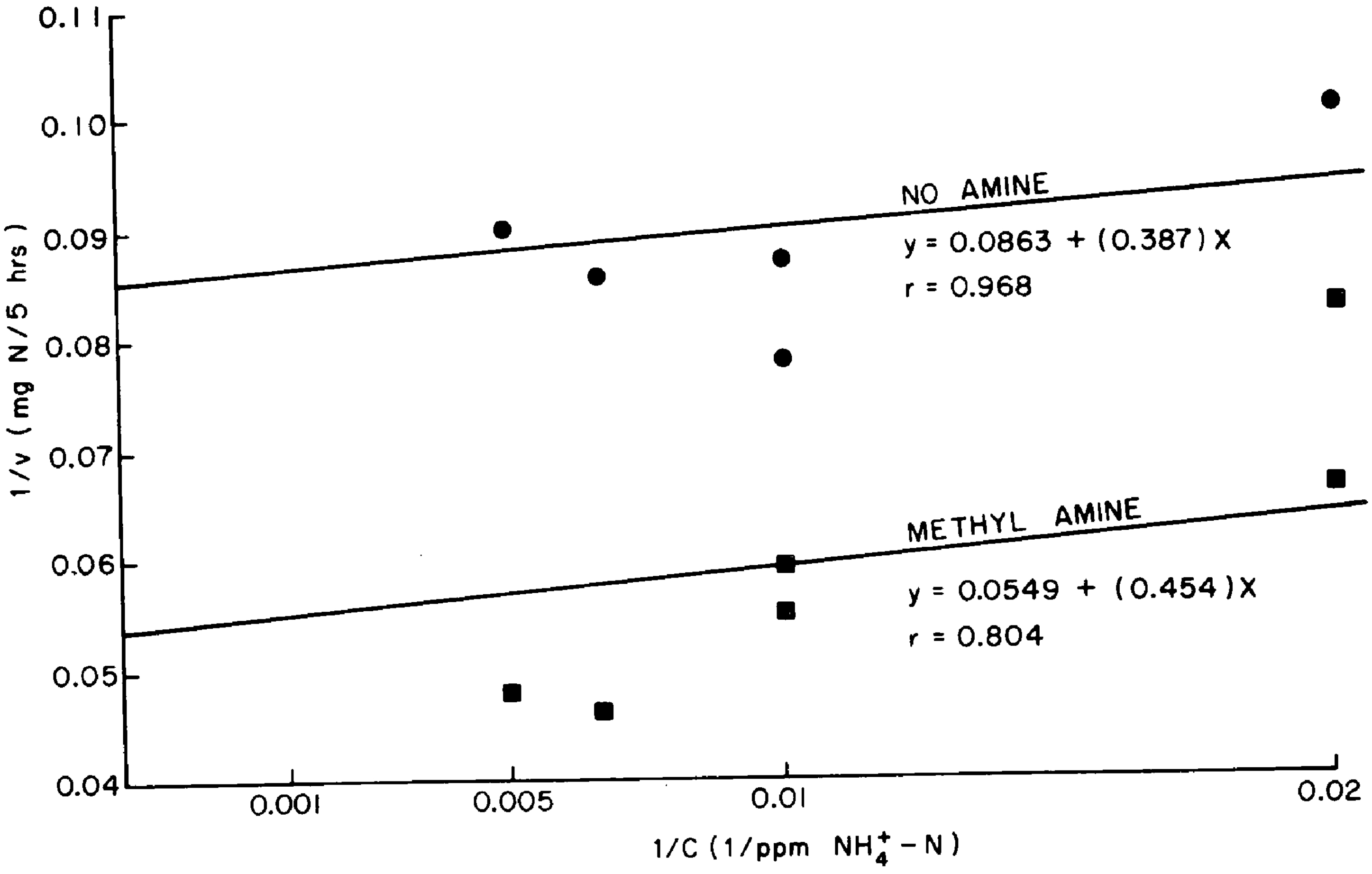

Figure 23. Effect of methyl amine on *C. ellipsoidea* ammonium-N uptake.

Methyl amine also affected the alga's photosynthetic and respiratory processes. Methyl amine concentrations of 2.5 ppm or less stimulated oxygen production (Figure 24). The oxygen concentrations shown are apparent oxygen levels; correction was made for temperature, pressure, and solution phase oxygen, but not for respiratory consumption. With more than 2.5 ppm of methyl amine, oxygen production decreased rapidly with the increase in amine concentration. Algal oxygen production was decreased by one-half at about 9 ppm amine-N. The amine also stimulated the respiratory consumption of oxygen. During the 4-hour incubation period with no amine added, 0.65 ml of oxygen was consumed (Figure 25).

Aliphatic amines have been shown to inhibit isolated plant chloroplast photophosphorylation (ATP synthesis). Even very high concentrations of methyl amine (500 ppm) did not inhibit photosynthetic ATP synthesis in intact C. *ellipsoidea* cells. Apparently, aliphatic amines affect the metabolism of isolated chloroplasts and algal cells differently.

Chemical equilibria provide a method for describing the physical and chemical behavior of aliphatic amines and ammonia in aqueous systems. Close inspection of chemical equilibrium of gaseous amines with aqueous surfaces suggests that volatile aliphatic amines from the atmosphere are highly capable of concentration into aqueous systems. These calculations demonstrate that amines can concentrate in surface waters from the atmosphere. Analysis of lake waters located near a large cattle feedlot showed seasonal fluctuations in amine and ammonia concentrations, but no large accumulation (Table 34). The compounds may be metabolized by microorganisms or adsorbed by lake sediment.

To determine if there are organisms which decompose aliphatic amines present in surface waters and sediment, samples of lake sediment and water were incubated in the laboratory with methyl and dimethyl amines. Both amines were readily degraded, with methyl amine being degraded more rapidly than dimethyl amine.

The organisms in lake water and sediments may account for the lack of an accumulation of amines in such waters located near cattle feedyards. Apparently, microorganisms rapidly metabolize the amine-N, thus entering this N into the N cycle of the aquatic system. This idea is supported by the concentrations of amines measured by periodically analyzing lake waters during the year (Table 34). During cold weather (periods of low microbial activity), amine concentrations were highest. The amine concentrations decreased as the seasonal temperatures increased.

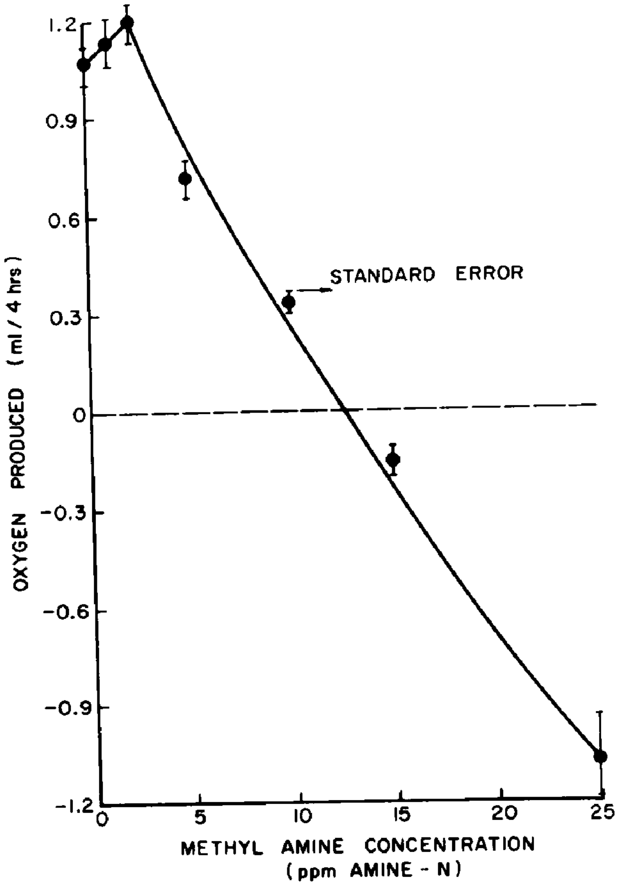

Figure 24. Effect of methyl amine on *C. ellipsoidea* photosynthetic $O_2$ production.

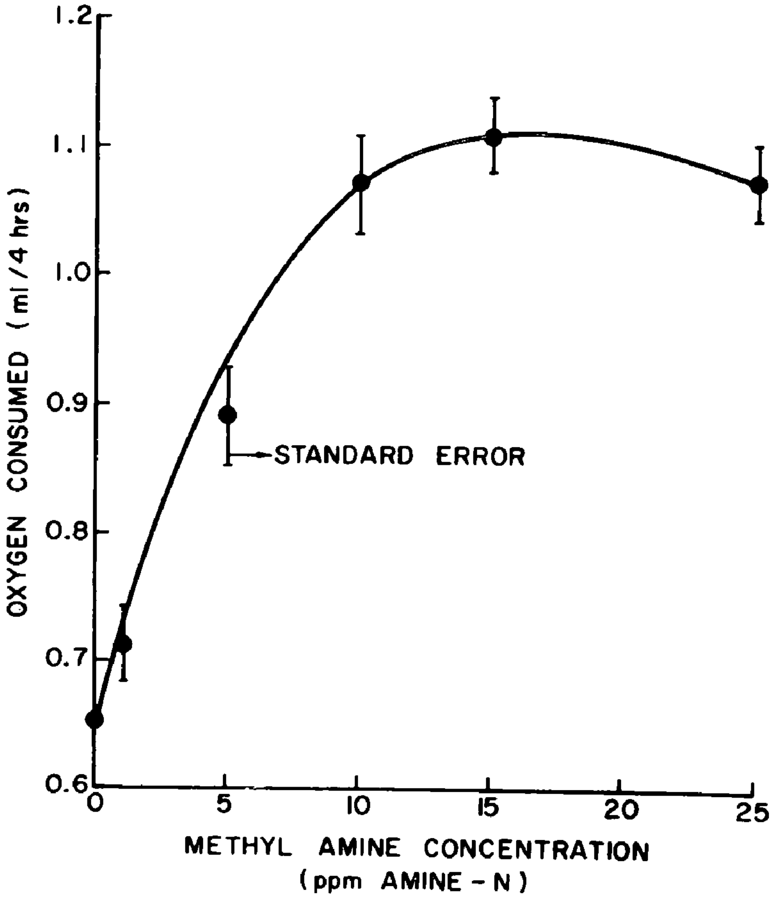

Figure 25. Effect of methyl amine on *C. ellipsoidea* respiratory $O_2$ consumption.

Table 34. TOTAL DISTILLABLE N AND ALIPHATIC AMINE CONTENT OF A LAKE LOCATED NEAR A CATTLE FEEDLOT[a]

| Date of Sampling | Total Volatile N (ppm) | Total Amine-N (ppm) |
|---|---|---|
| 3- 2-73[b] | 3.7 | 0.183[c] |
| 4-19-173[d] | 0.65 | 0.052 |
| 7- 5-73 | --[e] | 0.018 |
| 8- 8-73 | --[e] | --[f] |

[a] Located about 2 km east of a 90,000-unit feedlot

[b] Lake was covered with about 10 cm ice.

[c] Composed of four identifiable amines: methyl, 94 ppb; dimethyl, 41 ppb; ethyl, 46 ppb; and isopropyl, 2 ppb.

[d] No ice remaining on lake.

[e] No measurable volatile N.

[f] No detectable amine.

## NEBRASKA

### Significance of Sulfur Compounds

Attempts to control odors and gases from beef cattle feedlots and other beef-confinement areas have been mostly unsuccessful. Accordingly, we must take a more basic approach to the problem. This involves identification, quantification, and source delineation before control measures can be devised. To date, only $NH_3$ and presumptive evidence showing amines are volatilized from beef cattle feedlots have been reported (7, 33). Therefore, more work is needed to identify odor compounds from beef cattle manure and feeding areas.

The purpose of the following studies was to identify and quantify some of the sulfur compounds and gases emanating from anaerobically incubated bovine manure. These studies were conducted in anaerobic columns and in the feedlots. The compounds were measured with gas chromatography.

Carbonyl sulfide (COS) and hydrogen sulfide were detected above the anaerobic manure (Figure 26). Carbon dioxide, $CH_4$, and $O_2$ were measured also (Figure 27).

About 0.1 ppb of COS was detected in gas samples from caissons beneath the solids retention basin of a broad-basin terraced feedlot. The feedlot installation has been described previously. The gas was detected also from the surface of the basin but not from the liquid retention pond. These results show COS is produced in the feedlot (50).

Carbonyl sulfide has not been reported from manure or feedlots previously. It is present in natural gas (51) and in the gases from some volcanoes (52). The gas is toxic to the central nervous system and decomposes to $H_2S$ (53). It is speculated that COS could be an intermediate in the sulfur scheme of bacteria. It is too early to assess the importance of COS in the feedlot. Carbonylsulfide may be important in closed confinement units; however, this would depend on the concentrations produced. Carbonyl sulfide might be a precurser to $H_2S$ and more information is needed on such chemical reactions.

The results also show $H_2S$ and COS can be detected in very low concentrations which will be useful for management-system assessment.

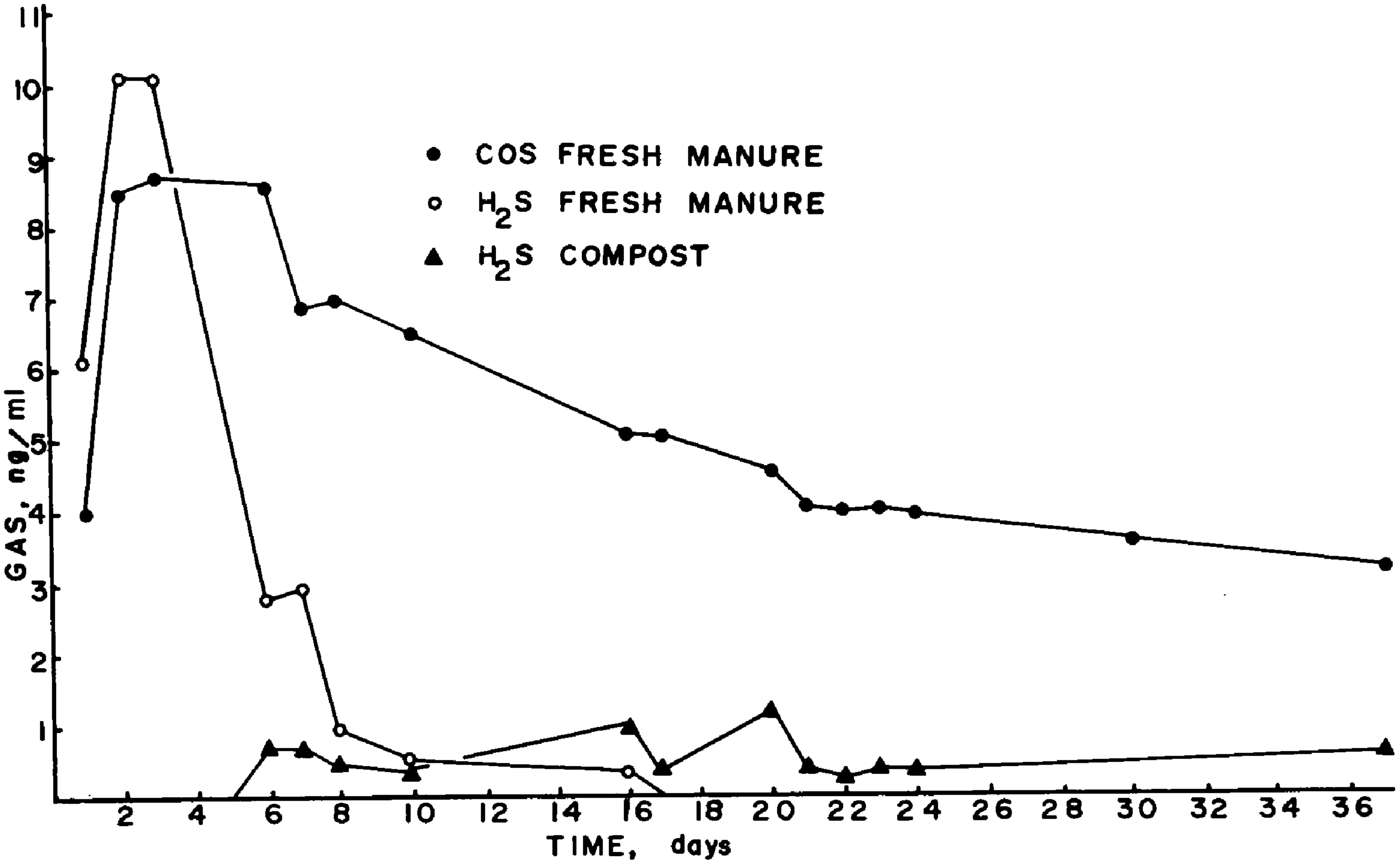

Figure 26. Production of carbonyl sulfide (COS) and dihydrogen sulfide ($H_2S$) from anaerobically incubated manure and compost.

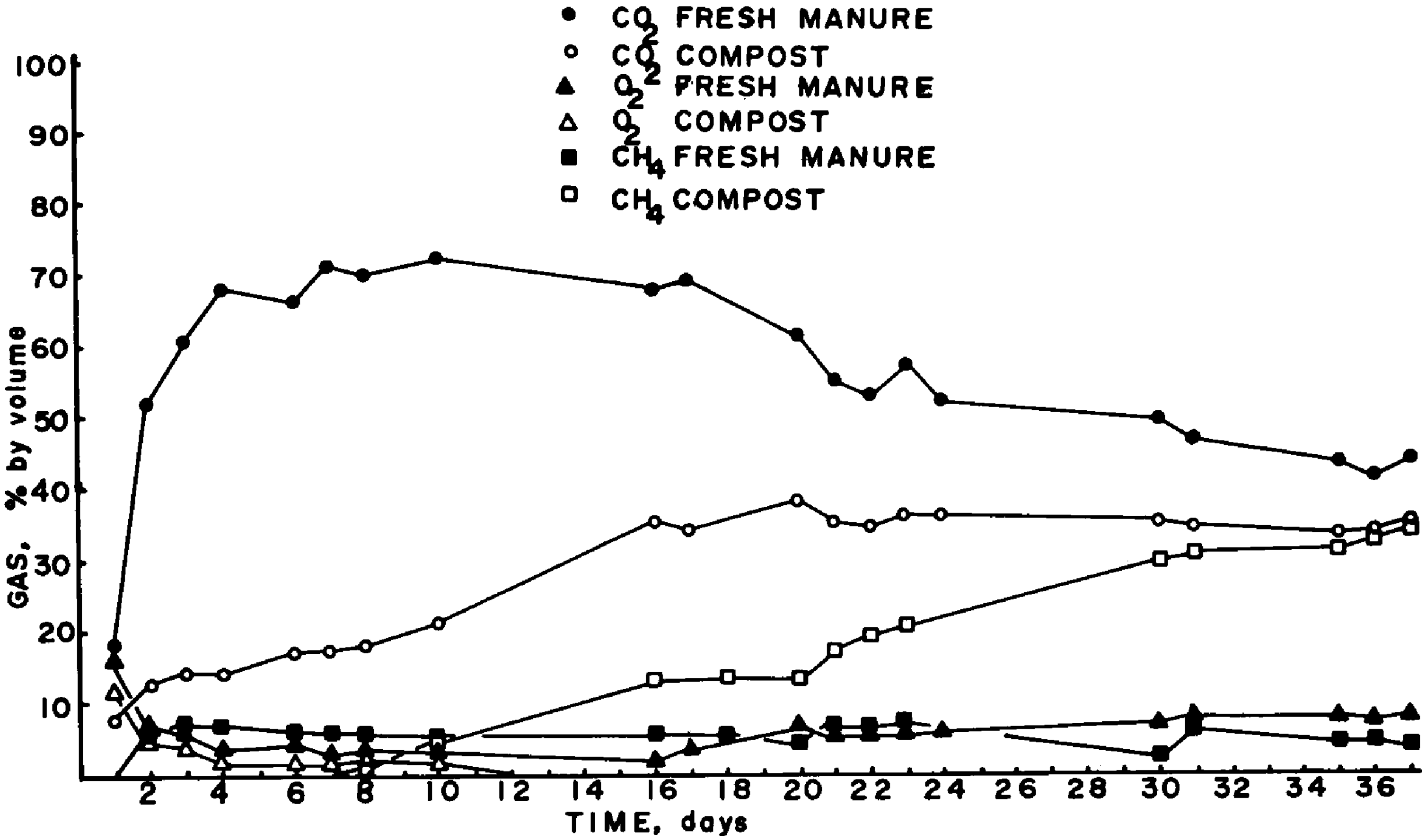

Figure 27. Gases present above anaerobically incubated manure and compost.

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## TECHNICAL REPORT DATA

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7. AUTHOR(S) L. K. Porter, F. G. Viets, Jr., T. M. McCalla, L. F. Elliott, F. A. Norstadt, H. R. Duke, N. P. Swanson, L. N. Mielke, G. L. Hutchinson, A. R. Mosier, and G. E. Schuman

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13. TYPE OF REPORT AND PERIOD COVERED

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15. SUPPLEMENTARY NOTES

16. ABSTRACT Climatic factors, feedlot runoff, and organic material in the runoff were evaluated in experimental and commercial feedlots. The effects of slope, stocking rates, terraces, basins, and holding ponds were evaluated to obtain the best controls for containing runoff. In eastern Nebraska, 70 cm annual precipitation produces 23 cm of runoff; whereas, in northeastern Colorado, 37 cm annual precipitation gives only 5.5 cm of runoff. Large applications of runoff liquid, up to 91 cm on grass-Ladino and 76 cm on corn, in Nebraska did not decrease yields; however, in northeastern Colorado, the concentrated high-salt runoff required dilution before direct application to crops. The organic manure-soil interface severely restricts the movement of water, nitrates, organic substances, and air into the soil beneath feedlots. The amounts of $NO_3$-N in soil cores taken from Nebraska feedlots and croplands ranked as follows: abandoned feedlots > feedlot cropland > upland feedlots > river valley feedlots > manure mounds > alfalfa > grassland. Feedlots contribute $NH_3$, amines, carbonyl sulfide, $H_2S$, and other unidentified substances to the atmosphere. Ammonia and amine can be scavenged from the air by green plants and water bodies. Anaerobic conditions in feedlots are conducive to the production of carbonyl sulfide, $H_2S$, and amines. Management practices, such as good drainage, that enhance aeration will decrease the evolution of these compounds.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Agricultural wastes<br>Cattle<br>Livestock<br>Waste disposal | Rainfall runoff<br>Animal wastes<br>Feedlots<br>Land application<br>Water pollution potentials<br>Wastes characteristics | 02/03<br>02/04<br>02/05 |

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