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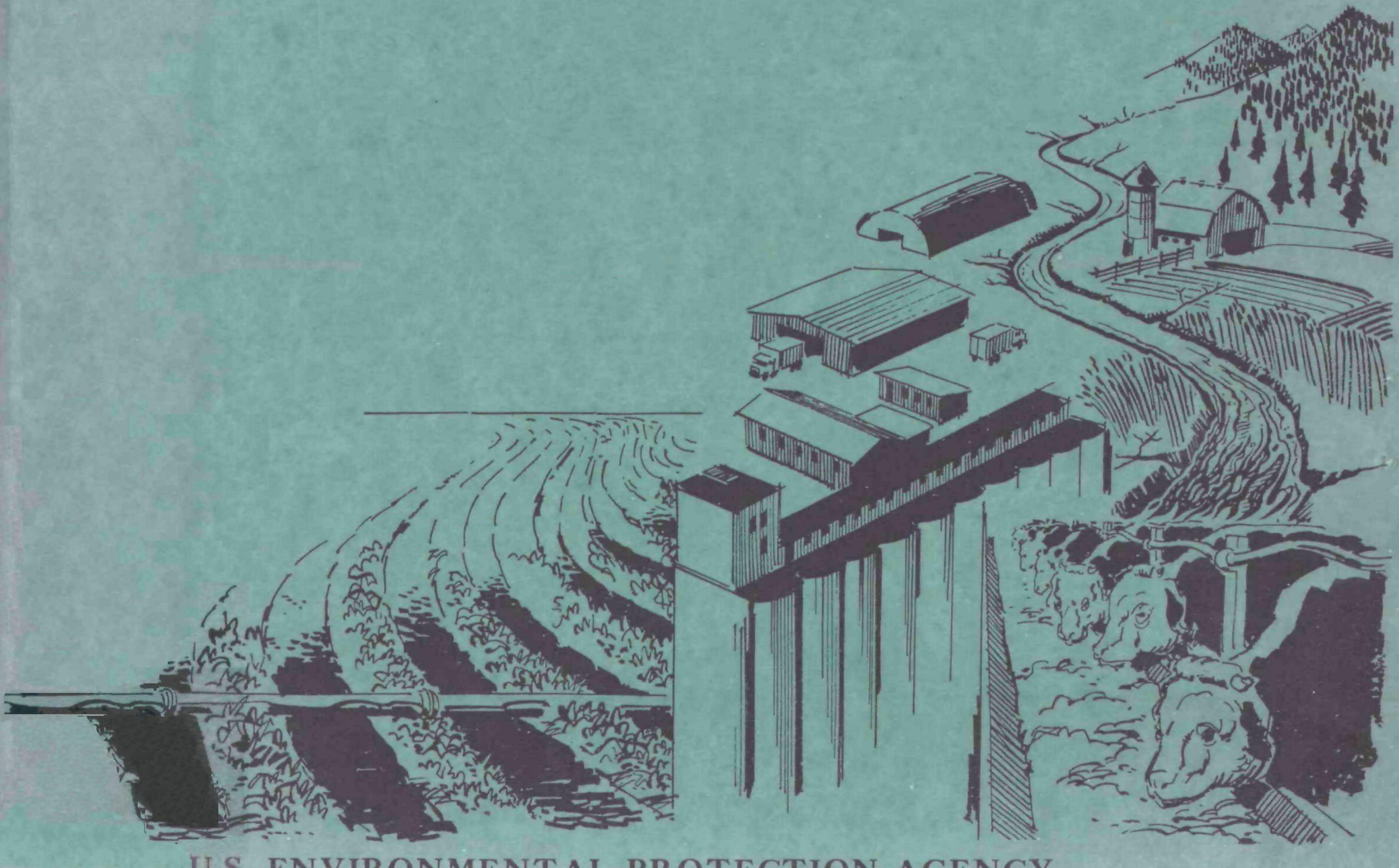
CHARACTERISTICS OF WASTES FROM SOUTHWESTERN CATTLE FEEDLOTS



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CHARACTERISTICS OF WASTES FROM SOUTHWESTERN CATTLE FEEDLOTS

by

Texas Tech University
Water Resources Center
Lubbock, Texas 79409

for the

ENVIRONMENTAL PROTECTION AGENCY

Project #13040 DEM

January, 1971

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price $1.00

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ABSTRACT

Research was conducted to determine the characteristics of waste from Southwestern cattle feedlots. Experimental feedlots located on the Texas Tech Campus were used in performing the studies. The feedlots were generally operated in a manner conforming to normal commercial feeding operations in the area. They were provided with collection pits that allowed the quantity of runoff to be measured accurately, and samples of runoff were collected routinely both during rainstorms and from the collection pits. Manure samples were also collected routinely for analysis.

Results of the research show that the quantity of runoff per unit area of concrete-surfaced lots is substantially greater than the quantity per unit area of dirt-surfaced lots, and that the concentrations of pollutants in concrete lot runoff are substantially higher than corresponding concentrations in runoff from dirt-surfaced lots.

The quantity of solid waste derived from cattle being fed an all-concentrate ration is less than half as great as the quantity derived from cattle being fed a 12 percent roughage ration. Additional studies showed that all solid waste derived from cattle feeding operations are readily compostible, although the rate of composting is influenced to some extent by the type of ration, moisture content of the waste on the feedlot floor, and other factors.

Agronomic studies indicate that runoff can be used for irrigation of crops, but extreme caution is required in the application of runoff to crops to prevent damage to them.

This report was submitted in fulfillment of Project No. 13040 DEM--Rev. under the partial sponsorship of the Environmental Protection Agency.

CONTENTS

Page

Page

FIGURES

TABLES

Page

CONCLUSIONS

The conclusions contained herein were derived from careful consideration of data obtained in laboratory and field studies. They are limited by the scope of the project and by the methods used, and are applicable to the cattle feeding industry of the Southwest. They may not in all cases apply directly to other regions of the United States.

1. The concentrations of pollutants in runoff derived from precipitation on Southwestern cattle feedlots are influenced to some extent by factors such as ration composition, antecedent moisture conditions, depth of manure, slope of lot, and density of cattle, but such variations are of no real significance from the standpoint of water quality control. Pollutant concentrations are in the range of one to more than two orders of magnitude higher than those normally found in untreated municipal sewage.

2. Treatment, by conventional anaerobic or aerobic systems, of runoff derived from precipitation on Southwestern cattle feedlots is infeasible because of the very high concentrations of pollutants in such runoff and, more importantly, because of the extremely erratic frequency with which runoff occurs. In no case should this runoff be released to surface water.

3. Concentrations of pollutants in runoff resulting from precipitation on concrete-surfaced lots are two to four times greater than corresponding concentrations derived from dirt-surfaced lots.

4. The quantity of solid waste accumulating on the feedlot floor is a direct function of the fraction of roughage in the finishing ration. Mean solid waste accumulations of 2.3 pounds per head per day (dry weight basis) were obtained from cattle on an all-concentrate ration, 4.4 pounds per head per day from cattle on a ten percent roughage ration, and 5.0 pounds per head per day from cattle on a 12 percent roughage ration.

5. The fraction of incident precipitation that runs off concrete lots is about twice the fraction that runs off dirt-surfaced lots. Decreased roughage concentration increases the quantity of runoff on concrete-surfaced lots.

6. Stocking rates above 40 square feet per animal on concrete-surfaced lots do not appear to enhance animal performance. At this stocking rate, the quantity of runoff per animal is somewhat less than the corresponding quantity derived from cattle on dirt-surfaced lots at conventional stocking rates using the same ration.

7. Limited feeding trials utilizing a roof to eliminate runoff showed no apparent beneficial or detrimental effects on cattle performance.

8. Increasing the slope of concrete-surfaced feedlots from 7-1/2 to 15 percent made the lots virtually self-cleaning without any apparent adverse affect on animal performance.

9. Treatment of accumulated solid wastes from Southwestern cattle feedlots by aerobic composting is technologically feasible regardless of the type of operation. However, the rate of composting varies with type of ration, moisture content of waste, etc.

10. Extreme caution must be exercised in the application of feedlot runoff to agricultural crops. Preplant applications seriously inhibit seed germination and application to seedling crops seriously damages the crops. With proper timing, limited applications can be made to most well established crops. Repeated applications of runoff to soil results in a buildup of Na^+, Cl^-, and other ions in the soil.

RECOMMENDATIONS

From the literature and by general recognition, the following recommendations and design criteria are applicable to Southwestern beef cattle feedlot waste management:

Beef cattle feedlot waste management involves two basic interrelated pollutional problems, (a) the management, removal and disposal of the solid waste that accumulates on the feedlot surface and (b) the treatment and disposal of the liquid runoff resulting from precipitation. Disposal of both solid and liquid wastes should be accomplished in a way that will prevent undue pollution of the environment.

1. All surface water should be prevented from flowing into the feedlot area. This may be accomplished by use of an appropriate system of diversion channels, terraces, or ditches.
2. The feedlot should have a minimum slope to provide surface drainage. The slope should be uniform to prevent localized channeling. Each lot should drain directly into a drainage channel without flowing across adjacent lots.
3. Runoff storage pits should be lined if located in a porous type soil to prevent possible pollution of underground water.
4. The spreading of runoff water on a porous soil surface should be limited to light irrigation applications to prevent movement of pollutants into the soil column.
5. Undiluted runoff should not be applied to soil as a preplant irrigation, and it should not be applied to seedling plants. Caution should be used in spreading runoff on any types of growing crops.

From the results and conclusions of this investigation, these further management considerations can be recommended.

1. Reducing the roughage content of finishing rations for cattle from 12 percent to zero would alone eliminate approximately one-half of the solid waste accumulation on the feedlot surface.
2. The feedlot could be covered to eliminate runoff. No runoff occurs from roofed feedlots provided that roof drainage does not flow through the accumulated waste.
3. Frequent cleaning of concrete feedlot surfaces results in a less polluted runoff provided cleaning takes place before the lot surface is completely covered with waste. After the

lot is covered, further accumulation does not materially affect the quality of runoff.

4. A concrete-surfaced feedlot offers the possibility of decreased area for each head of livestock on feed. By reducing area requirements to 40 or fewer square feet per head, the quantity of runoff from a feedlot holding a given number of animals is reduced.

5. Increasing the slope on concrete feedlots to about 15 percent makes them essentially self-cleaning provided a means is available for removing the solid waste that accumulates on the lower side, and provided the lots are not too long.

6. Land disposal is probably the only economically feasible method of ultimate disposal of solid waste at this time. Consideration should be given to the availability of land for waste disposal in selecting the feedlot site.

7. Consideration should be given to composting solid waste as a normal part of the feedlot operation to reduce the land, air, and water pollution potential of the accumulated waste, and to reduce the volume of the accumulated waste.

8. It is recommended that further studies be made to determine the feasibility of utilizing a roof, steeply sloped floors, slotted floors, and various types of automatic waste handling systems under actual feeding conditions. It is therefore recommended that a highly flexible pilot plant be built to test these systems and to determine the optimum design of feedlots for the Southwestern part of the United States.

INTRODUCTION

The cattle feeding industry studied in this project is located on the South High Plains Region of Northwest Texas at an altitude generally in excess of 3000 feet. The South Plains is a segment of the Llano Estacado bordered on the north by the Canadian River, on the east by the caprock escarpment, and on the west and southwest by the Pecos River.

The drainage surface is generally featureless except for small playas and small stream valleys. The numerous shallow playas that dot the area fill during periods of precipitation to form small lakes. A few dry stream valleys of Brazos River tributaries constitute the only surface water flow from the area.

The climate is semi-arid transitional, ranging from the more humid climates of the east and south to the desert climates of the west. The normal precipitation averages about 18 inches per year. Most of the rain occurs during May, June, and July and during late August, September, and October when warm moist tropical air from the Gulf of Mexico flows over the area. Thermal convection flow of this moisture laden air mass results in moderate to heavy afternoon and evening thunderstorms. During winter months the occasional light snow remains on the ground only a short period of time. In general, precipitation is erratic and ranges from over 40 inches to less than 9 inches per year. Monthly values from 0 to 14 inches have been recorded.

The normal annual temperature is about 60 degrees Fahrenheit with a normal daily maximum in July in the nineties, and a normal daily minimum in January in the twenties. The mean wind speed is very high since the uniform topography offers little resistance to surface air flow. The high average rate of air movement and the generally low humidity result in a high evaporation rate for the region. The high altitude and generally clear skies allow for a rapid radiation from the ground surface during nighttime periods. The rapid cooling of the evening hours and the high solar radiation of the daylight hours usually provide average diurnal swings of 30 degrees Fahrenheit.

The water supply for nearly all agricultural, municipal, and industrial consumers is the Ogallala Aquifer which underlays most of the South High Plains. The Ogallala is a relatively thin aquifer with a maximum saturated thickness of 350 feet. At present the water table, on the average, has been drawn down about 100 to 125 feet.

The commercial production of slaughter cattle in the High Plains of West Texas has increased from about 500,000 head in 1960 to a current production of almost four million head per year. This phenomenal rise in production has occurred because of the availability of abundant supplies of both feeder cattle and grain sorghum, and the realization by local interests that it was uneconomical to ship both feeder cattle and feed grains out of the area for subsequent conversion of grain into beef. Only two states, Iowa and Nebraska, currently produce more fed cattle than the High Plains of West Texas, and feedlots now on the drawing boards for West Texas will soon make this area preeminent in the production of fed beef cattle.

In the early stages of the growth of the feedlot industry in West Texas, feedlots tended to locate on the few streams in the area. Tierra Blanca Draw, which runs through the south portion of Hereford, Texas, was the focal point of much of the initial concentration of feedlots. More recent practice has been to locate feedlots so that drainage runs to a playa lake located on the property of the feedlot owner. This practice has undoubtedly lessened the pollution problem so far as surface water is concerned, but it has also undoubtedly resulted in an increase in the potential for pollution of groundwater in the High Plains area.

The water pollution problems associated with cattle feedlot operations in the High Plains area are not the same as those found in the Corn Belt of the Midwest. Much of the cattle feeding in the Corn Belt is located on the individual farm site where it provides supplementary income and converts a portion of the farmer's crop into a higher priced product. The average number of cattle marketed per feedlot in the Corn Belt is under 100 head annually, whereas individual feedlots in Texas market an average of about 1700 per year. Over 13,000 head per feedlot are marketed annually in Arizona.

In addition to differences created by high volumes of waste and density of deposition, the climatic factors of the High Plains as related to the characteristics of feedlot wastes are considerably different from those of the Midwest. The limited rainfall in the area is concentrated in two short periods during the spring and fall as previously noted. Short periods of high intensity rainfall result in high rates of runoff in late spring and early fall. These periods are followed by long dry periods of low air moisture and little precipitation. During this time the urine and feces accumulate on the feedlot surface in a dehydrated form resulting in a waste high in accumulated salts. Because of rapid dehydration the accumulated waste exists in a relatively inert form that can be readily converted almost to its original condition by the simple addition of moisture.

Project Objectives

The overall objective of this study was to plan and conduct investigations which would determine the characteristics of beef cattle feedlot wastes in a semi-arid climate.

More specifically, the objectives were:

A. To determine the quantity and quality of runoff from Southwestern beef cattle feedlots.

B. To develop recommendations and design criteria for Southwestern beef cattle feedlot waste management control.

Scope

Cattle feeding facilities consisting of both dirt and concrete-surfaced feedlots and controlled environment chambers located on the Texas Tech University farm were used in the studies. The conventional feedlots were operated in a manner conforming to normal commercial operating practice of the area. Runoff was collected in pits according to current recommendations of the Texas Water Quality Board.

The cattle in the controlled environment facilities were fed an all-concentrate ration, and the wastes produced by these cattle were flushed out with water on a daily or every other day basis and collected in a 55 gallon drum located adjacent to the facility. Additional studies were conducted using a feedlot in which cows were fed a maintenance ration consisting primarily of silage.

REVIEW OF PREVIOUS WORK

In the twenty-two major cattle feeding states, fed cattle marketings have expanded from approximately 12 million head in 1969 to 17 million head in 1964, and to 23.7 million head in 1969. The growth of this industry has been in feedlots with a capacity of 1,000 head or more. (Western Livestock Marketing Information Project, 1970). The intensification in numbers of cattle per feedlot has been followed by numerous situations which have been magnified to the point of needing new concepts for optimum and efficient management. One of these areas is the handling and disposal of cattle feedlot waste. The volume of daily waste accumulation per animal has been observed to range from as low as 2.3 pounds when feedlot cattle consumed an all-concentrate finishing ration (Grub et al., 1969) to a reported 8.1 pounds for bovine wastes in general (Okey, Rickles and Taylor, 1969). McCalla and Viets (1969) stated that 10,000 head of cattle on a feedlot produce 260 tons of solid waste and 100 tons of liquid waste daily. This amounts to a total of 72 pounds per head per day.

The potential pollutional characteristics of animal waste and runoff water from feedlots have been recorded by Henderson (1962), Taiganides (1963), Willrich (1966), and Loehr (1968b). Incidents of groundwater pollution (Loehr and Agnew, 1967; Loehr, 1968a; Hart et al., 1970) and fish-kills (Smith and Miner, 1964; U. S. Department of HEW, 1965; U. S. Department of the Interior, 1966; Kansas Forestry, Fish and Game Commission, 1967) which have been directly attributed to runoff from livestock feeding operations have been instances of concern. It is documented (N.R.C., 1966) that the elimination of wastes as a discharge material generally intrudes upon a natural resource or someone's personal rights.

Characteristics of Cattle Feedlot Waste

Grub et al. (1969) summarized data from various sources which indicated that the type of ration, size of cattle, concentration of cattle per pen, slope and surface covering of the lot, depth of accumulation, and moisture content of the waste were some of the major factors affecting the composition and quantity of cattle feedlot waste. Gilbertson et al. (1970) found that animal density and surface slope influenced the characteristics of runoff and solid waste from unpaved beef feedlots. Several workers have reported data on the quality of runoff from cattle feedlots, among those being Miner et al. (1966), Miner, Lipper and Erickson (1967), Loehr (1969b), Grub et al. (1969), Norton and Hansen (1969), Wells et al. (1969b), and Gilbertson et al. (1970). These papers varied somewhat with respect to actual numerical values reported for many of the parameters, but consistently agreed that runoff from cattle feedlots was highly concentrated and carried a high pollution potential.

Pollution of water usually refers primarily to surface water, but pollution of groundwater from cattle feedlots seems to be a definite possibility (Smith, 1965; Stewart et al., 1967; Engberg, 1967; McCalla and Viets, 1969; Wells et al., 1969). The work of Gilbertson et al. (1970) indicated movement of pollutants into the soil under unpaved feedlots, but considerable nitrate movement in the buffer strips between test lots. Other information would support the concept that contact surfaces are sealed by a film or slime layer which prevents seepage of water from feedlot surfaces, ponds, playa lakes, and dikes into the groundwater supplies (Lehman, Stewart and Mathers, 1970).

Handling and Disposal Methods

Feedlot waste can be partitioned into liquid and solid elements. The liquid portion is generally observed as a component of the accumulated waste on feedlot surfaces, as runoff during periods of rainfall, or as the carrier in liquid handling systems. Solid waste can be found on the feedlot surface, as a suspension in runoff water, as sediment in retention ponds, or as a suspension in liquid handling systems. Loehr (1968b) and Jones (1969) have summarized the concepts, methods, and problems associated with the handling and disposal of animal wastes.

Land Utilization. Application of feedlot waste to the land has been an accepted and common method of disposal. A general pattern of feedlot waste and runoff handling and disposal for Southwestern cattle feedlots is described as follows. Solid waste is often stockpiled within the cattle pen or in a central storage area near the feedlot. The material might be spread out to dry prior to stockpiling. The solid waste is then spread on fields as cultural practices and weather conditions permit. The waste is turned under or worked into the soil as soon as possible after spreading to reduce the chance of groundwater pollution. Runoff water is trapped in retention ponds or dikes, then pumped into a field irrigation system as a mixture with well water, or into shallow lagoons or ponds for evaporation. Owens et al. (1969) discussed the physical and economic relationships of these runoff and disposal procedures. Wells et al. (1969b) have described the toxic effects of application of undiluted feedlot runoff to selected crops.

Liquid handling systems for animal waste have evolved with the development of confined livestock operations. Confined production of fattening cattle has resulted in the need for critical evaluation of this system. Okey, Rickles and Taylor (1969) compared the relative economics of disposal of feedlot waste by selected wet and dry techniques. Their findings indicated that wet systems would be more expensive than those systems designed to handle solids. Liquid handling of feedlot waste would require adequate holding facilities to allow greater flexibility in the schedule for spreading (Loehr, 1968b). Liquid waste systems are generally holding and handling methods, with disposal of the liquid material by one or more of the methods discussed later. Data for cattle feeding systems are limited, but the information reported for other livestock production units would indicate that disposal of liquid waste is being accomplished by spraying on the land with an irrigation system, spreading by flood irrigation, spreading on the land from bulk tank trailers equipped with a sprayer system (Loehr, 1968b; Ward and Jex. 1969; Casler, 1969; Walker and Pos, 1969; Garold Parks, personal communication), or by application of the liquid waste under the soil (Reed, 1969).

Detailed information is lacking concerning optimum and maximum levels of soil application of solid or liquid feedlot waste, the effects of long-term application upon the soil, necessary land area per feedlot animal, economics of the method, effects of regional and seasonal influences, acceptable social relationships, and critical comparisons with other animal waste disposal systems. Use of this method seems to be limited to the amount of nitrogen applied per hectare of cultivated land. One report stated that approximately 72 kg of nitrogen from feeder cattle was the maximum amount per ha (Jones, 1969). Another source (Gray, 1969) illustrated that application rates of feedlot solid waste varied from as little as five tons per acre per year to as much as 300 tons per acre per year. Webber and Lane (1969) reported that two beef animals (weighing 181 to 500 kg) would excrete 64 kg of N in 365 days and would require 0.405 ha as the minimum land area in continuous corn for the efficient use of added nitrogen from manure, but only 0.202 ha as the minimum land area in continuous corn for the maximum application of nitrogen from manure which would not reduce corn yield or cause water pollution. Wells et al. (1969b) and Gilbertson et al. (1970) have raised questions concerning possible toxic levels of certain minerals. Many of the disposal systems to be mentioned culminate with disposal of residue on the land.

Anaerobic Digestion. The biological degradation efficiency of this process seems to be dependent upon the type of ration and animal (Loehr, 1968b). Laboratory studies have shown that loading rates of 45 g to 180 g of total solids per cubic foot have been successful with beef cattle wastes (Loehr and Agnew, 1967). Jeffrey, Blackman and Ricketts (1963) and Hart (1963) have demonstrated that beef cattle wastes can be treated by this method. Gases produced from this system contain between 50 and 70 percent methane. Field units have generally not been as successful as laboratory units and this difference has been atributed to the more complete mixing and more closely controlled temperatures of laboratory tests (Loehr, 1968b). In some instances, low temperatures in cold climates have been responsible for failure and incomplete digestion (U. S. Department of HEW, 1965; Berry, 1966). This type of treatment of municipal sewage (anaerobic sludge digester) is one of the most difficult systems to operate (Jones, 1969). The effluent from this process would generally require further treatment before release into the environment (Loehr, 1968b).

Anaerobic Lagoons. Loehr (1968b) presented an extensive discussion on this system with reference to waste from animals of all species and the comments to follow were summarized from his review. Little information has been reported for cattle wastes. The main functions of anaerobic lagoons are to remove, destroy, and stabilize organic matter, but not necessarily to purify water. This system is used mainly for treatment of highly concentrated wastes. Gas and odor production are evident near one of the systems. An anaerobic lagoon is similar in function to a single-stage, unmixed, unheated digester. Loading rates, pH, temperature, depth of the lagoon, and mixing must be carefully controlled. In anaerobic lagoons, there is a relatively solids-free liquid layer above a layer of settled solids. Taiganides (1968) reported that most anaerobic systems studied and used to date have yielded disappointing results.

Aerobic Lagoons. Animal wastes have a high oxygen demand, requiring large surface areas and volumes. For example, a confinement unit holding 1,000 head of beef cattle would require an oxidation pond of at least 8 ha (Loehr, 1968b). If mechanical aeration were used, less land area would be required than with the oxidation pond (Loehr, 1968b; Jones, 1969).

Oxidation Ditch. The oxidation or Pasveer ditch has received new attention with the advent of confined beef cattle feeding facilities. Forsyth (1965) listed many modifications of the oxidation ditch: continuous, semicontinuous, batch, and use of side ditches as settling tanks. Excessive foaming has been reported with animal wastes, but odors were practically eliminated (Loehr, 1968b; Jones, 1969). Moore, Larson and Allred (1969) have reported using this method for stabilizing beef cattle wastes in a cold climate.

Aerobic Composting. The reason for aerobic composting would seem to be that solid waste from beef cattle feedlots could be stabilized to a point at which the material would be odorless, insects would no longer be attracted to the mass, bacteria of putrification would no longer be active, coliform bacteria would no longer be detected, and a reduction of internal temperature would occur (Taiganides, 1968; Wells et al., 1969a). After composting, virtually all (Loehr, 1968b) to 80 percent (Wells et al., 1969a) of the dry matter remains for further disposal, presumably to the land. In addition, provisions would need to be made for disposal of runoff water. Wiley (1964) reviewed the operation of three animal waste composting plants, one of which was windrow composting of the combined manure from 5,500 steers plus the wastes from a meat packing operation. Wells et al. (1969a) reported data obtained from studying the effects of feed, management, and climate upon the composting efficiency of beef cattle waste in open air piles and in a drum-type digester. Both reports indicated successful stabilization of wastes by composting with minimum costs involved.

Complete Treatment. Complete treatment of animal wastes would be required if the final effluent were to be discharged into or adjacent to surface water. Alternatives for the complete treatment of animal waste were suggested by Okey, Rickles and Taylor (1969). The high degree of purity required by this means of disposal would be paralleled by larger and more expensive facilities for treatment (Bernard, 1969).

Dehydration and/or Incineration. Aerobic and anaerobic systems reduce the pollution characteristics of animal wastes but do little to reduce the volume of material to be handled. Dehydration and/or incineration is an approach that would dramatically reduce the quantity of animal waste to be handled and the potential for pollution of water. The available literature deals with the combustion of poultry wastes. A discussion of this system was made by Ludington (1963) for poultry manure.

Nutrient Recycling. The feeding of animal waste to livestock offers an interesting approach to waste management. This practice would utilize waste as a feedstuff, with the concept of materials reutilization being practiced. Anthony (1970) presented a paper summarizing the use of animal waste as a feed.

European Methods. Extensive reviews of handling and disposal practices in Europe were published by Allred (1966), Morris (1967), and Meek, Merrill and Pierce (1969). The systems reportedly used in Europe were generally based on small numbers of livestock per unit of land and employed a modification of an aerobic system. Therefore, with the increased concentration of beef cattle in feedlots in the United States, the value of European experiences may be limited.

Miscellaneous Methods. Loehr (1968b) reviewed miscellaneous handling practices for animal wastes, such as the addition of chlorine, lime, or chemical coagulants, or the use of trickling filters. Application of these methods to the disposal of cattle feedlot waste would appear to be of doubtful significance.

Implications for the Future. Biniek (1969) presented a thought-provoking paper on the question of livestock production versus environmental quality. He pointed out that time may be limited to achieve equitable solutions to environmental pollution and that we must be adaptive, flexible, and innovative to master the challenge. Loehr (1968b) outlined some of the pollution hazards associated with livestock wastes which must have a solution. Clayton (1969) discussed animal waste in general and feedlot waste in particular, from the legislative point of view. He posed significant environmental problems associated with waste from this industry.

Research Needs. Scalf and Witherow (1969) summarized research needs for feedlot waste management with an emphasis on the need for application of present technology and knowledge as a rapid, useful, and essential step toward future solutions of water quality problems. They proposed that a suitable method for the management of cattle feedlot runoff might be a combination of pretreatment in an anaerobic lagoon, treatment in an oxidation ditch or aerated lagoon, and final disposal on the land. Complete treatment in the aerobic system was proposed to be given attention in order that stream disposal might be applicable for the effluent.

A review of current research projects and areas for future research of beef cattle wastes in the Plains states was prepared by the Great Plains Agricultural Council (1969). This report recommended that research efforts be intensified in five areas: air pollution -- from odors, ammonia, dust, and pathogens; land disposal -- influence of extended application of manure upon soil integrity; pollution under feedyards -- investigate deep percolation of nitrates, phosphates, and microorganisms; systems analysis -- production methods related to disposal techniques, considering parameters of climate, construction, feed, and possible zoning restrictions or relocation; complete economic evaluation of current alternatives for waste disposal; and socio-legal implications -- a well-defined approach to their solution.

Evans (1969) proposed plans for expansion or initiation of feedlot waste research in the areas of: microbial, chemical, and organic pollution of the atmosphere, soils, and surface and underground water supplies; development of systems for pollution control of runoff water and subsequent treatment of the contained runoff by aeration, activated microflora, or by precipitation of colloids; and field investigations of the effects of heavy manure applications on cropped and uncropped soils over a period of years. A later report indicated that some of these studies were being implemented (Evans, 1970).

King (1969) itemized several avenues that warranted research attention. Some of these not previously mentioned are: the development of joint treatment and disposal facilities by several producers or sufficient treatment to enable the effluent to be handled by municipal treatment plants; seek potential uses for animal wastes; land use planning; and development of more detailed information on the relationship of wastes to agricultural production.

Loehr (1969a) tabulated most of the research areas mentioned, but with emphasis upon giving attention to the definition of problem areas, or types of research that were most likely to benefit from accelerated effort, and the investigation of trade-offs between technical improvements versus their effect upon waste management activities.

Webber and Lane (1969) indicated that before significant progress will be made in the disposal of animal waste, the nitrogen cycle must be quantitatively characterized.

Gilbertson (1969) and Hart et al. (1970) postulated from their findings that economics must be involved with each investigation concerned with pollution control from animal agriculture.

New concepts for the management of feedlot waste are receiving attention. A two-stage anaerobic digester is being studied as a refined approach to the treatment of feedlot waste (Wells et al., 1969b). A system of complete flushing of the concrete surface of a 10,000 head commercial feedlot is being used with disposal of the effluent in irrigation water for Midland Bermudagrass pasture (Dwight Pittman, personal communication). Covering feedlots with a roof would eliminate runoff water, leaving only the solid waste for management. Use of feedlot waste as a resource material offers a challenging approach, such as construction material, phosphoric acid treatment for specialized fertilizer (Lasalle and Launder, 1969), or as a substrate for single-cell protein production for man and animals (Thayer and Yang, personal communication). Biodegradation of manure by housefly larvae with subsequent feeding of the insects as a protein source to livestock has been investigated with poultry (Miller and Shaw, 1969; Calvert, Morgan and Martin, 1970).

STUDIES WITH CONCRETE-SURFACED FEEDLOTS

Four concrete-surfaced feedlots, each measuring 30 ft by 36 ft and sloped at 7-1/2 percent in a southeasterly direction along the long dimension were used in conducting the studies. The concrete surface had a rough stiff-brush finish.

The four concrete lots were divided into two drainage systems with a concrete curbing separating the systems. Total water runoff from each pair of lots was collected in unlined collection pits immediately adjacent to the concrete surfacing. Instrumentation was installed to measure pit volume, to allow for sampling during periods of runoff, and to measure total precipitation, Figure 1.

Animal Feeding Studies

Three feeding trials were run in order to provide data required by the project. The feeding trials lasted for 173 days, 136 days, and 121 days, respectively. Approximately 40 days elapsed between the end of one feeding trial and the beginning of the next in order to provide time for cleaning the lots, analyzing all data collected, and purchasing and obtaining delivery of a new group of feeder cattle.

While a study of the performance of cattle under various feedlot management systems was not a part of this project in the strictest interpretation of the contract, its omission would have tended to have made any results obtained of questionable value. Throughout the project, emphasis was directed toward establishing the characteristics of wastes and developing economically feasible and workable systems for waste management, control and treatment of runoff, and solid waste removal. The data are therefore included in order to put the report in proper perspective.

Experiment I consisted of feeding 47 steers for 173 days. Mean initial weight was 525 pounds per steer. The 47 steers were approximately equally divided among four lots. The steers in two lots were fed an all-concentrate ration, and those in the other two were fed a 12 percent roughage ration. Ration compositions used are shown in Table 1, and the mean performance of the steers is shown in Table 2.

Experiment II utilized 80 heifers in a feeding trial of 136 days duration. Mean initial weight of the heifers was 475 pounds. Composition of the ration fed is shown in Table 1. The purposes of this experiment were to study the effects of cattle density, lot cleanliness, manure moisture content, and roof shelter on the performance of cattle and on the quantity and characteristics of wastes produced.

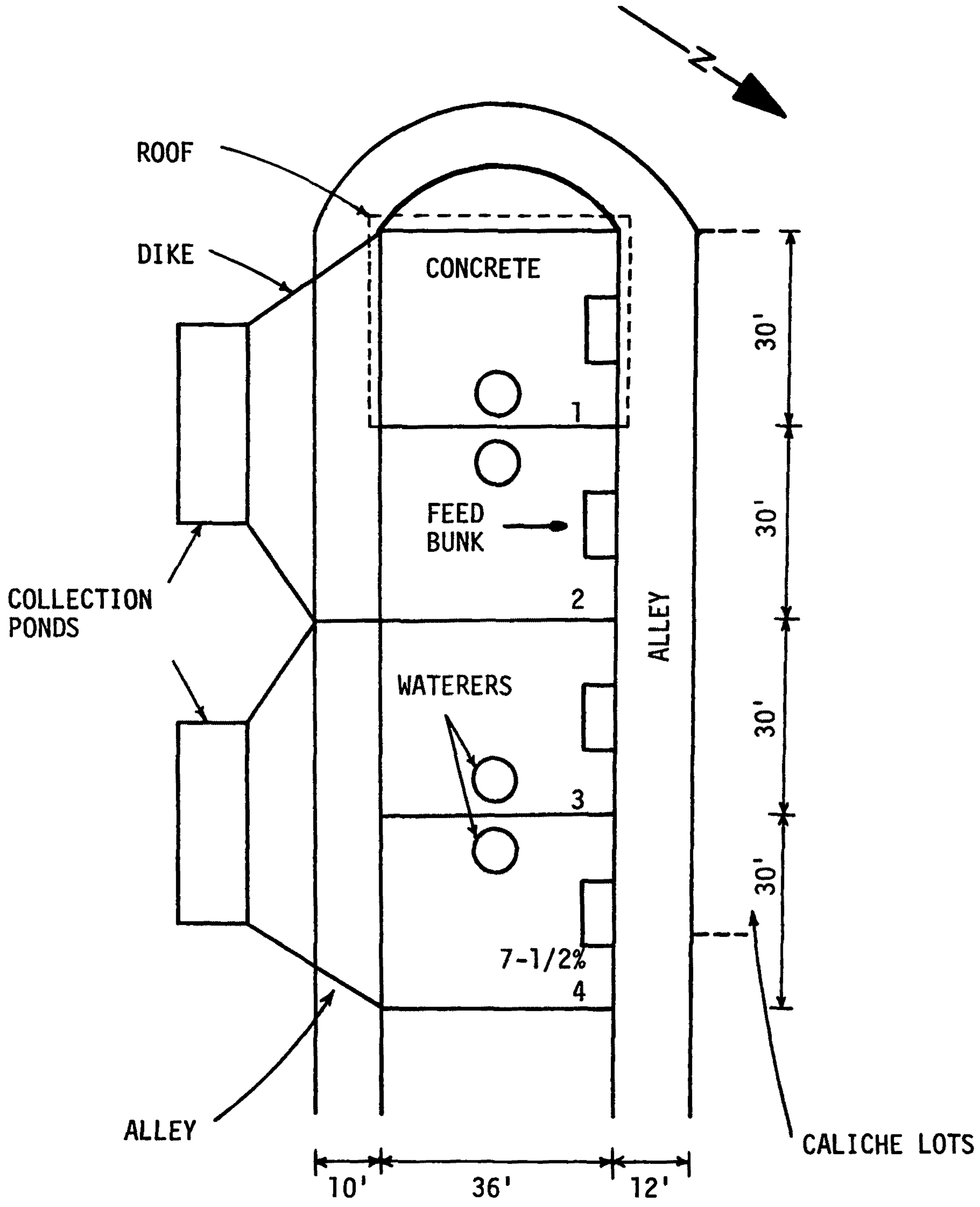

FIGURE 1. LAYOUT OF CONCRETE-SURFACED FEEDLOTS USED ON PROJECT.

TABLE 1. RATION COMPOSITION (percent, air-dry basis)

Ingredients	Experiment I All-concentrate	 12% Roughage	Experiments II & III 10% Roughage
As Fed			
Sorghum grain, dry rolled	90.81	74.75	76.00
Cottonseed meal (41%)	6.00	7.25	7.25
Cottonseed hulls	0.00	6.00	5.00
Alfalfa hay, chopped	0.00	6.00	5.00
Beef tallow	0.00	3.00	3.00
Premix T-272	3.00	2.75	3.75
Calcium carbonate	0.19	0.25	0.00
	100.00	100.00	100.00
Chemical			
Dry matter	89.64	90.03	89.87
Crude protein	11.9	11.9	11.9
Calcium	0.80	0.87	0.41
Phosphorus	0.28	0.32	0.37
Premix T-272 Composition		**Amount (lb)**	
Cottonseed meal		974.17	
Calcium carbonate		600.00	
Salt		400.00	
Vitamin A (325,000 IU/g)		1.13	
Stilbestrol (2 g/lb)		20.00	
Chlortetracycline (50 g/lb)		4.70	
		2,000.00	

TABLE 2. MEAN FEEDLOT PERFORMANCE OF STEERS IN EXPERIMENT I (POUNDS: 173 DAYS)[a]

Parameter	Treatments All-concentrate	 12% Roughage	% Difference
Number of steers	23	24	
Daily gain	2.47	2.61	5.4
Feed consumption	17.9	20.0	10.5
Efficiency (feed/gain)	7.00	7.67	8.7

[a] No statistical differences among the parameters ($P < .05$).

Before Experiment II was initiated, a sheetiron roof was placed over Lot No. 1, Figure 1. Cattle were then placed in Lot No. 1 at a density of 42 square feet per animal, in Lot No. 4 with a density of 41 square feet per animal, and in Lots 2 and 3 at a density of 84 square feet per animal. Lot No. 2 was kept continuously wet by periodic sprinkling, and Lot No. 3 was cleaned on a weekly basis. Mean performance of animals used in this experiment is given in Table 3.

TABLE 3. MEAN FEEDLOT PERFORMANCE OF HEIFERS IN EXPERIMENT II (POUNDS: 136 DAYS)[a]

Parameter	Treatments		% Difference
	Covered	Open	
Number of animals	26	27	
Daily gain	2.62	2.63	
Feed consumption	18.9	19.3	2.1
Efficiency (feed/gain)	7.21	7.35	1.9
	Continuously Clean	Continuously Wet	
Number of animals	14	13	
Daily gain	2.80	2.63	6.1
Feed consumption	20.2	18.7	7.4
Efficiency (feed/gain)	7.21	7.11	1.4
	Animal Density (square feet/animal)		
	41	84	
Number of animals	53	27	
Daily gain	2.63	2.72	3.3
Feed consumption	19.1	19.6	2.1
Efficiency (feed/gain)	7.26	7.17	1.2

[a] No statistical differences among the parameters ($P < .05$).

Experiment III investigated the effects of pen covering, density, and pen slope on animal performance. For this experiment, pens 1 and 4 (Figure 1) were each divided into two fifteen foot wide pens. The eastern most side of each pen was then rebuilt to provide a fifteen percent slope and a finish similar to that on existing lots.

Eighteen steers were put in each side of Lots 1 and 4, and Lots 2 and 3 each contained nine steers. The feeding trial was continued for 121 days. Mean performance of the steers under different slopes, densities, and shading conditions is shown in Table 4.

TABLE 4. MEAN FEEDLOT PERFORMANCE OF STEERS IN EXPERIMENT III (POUNDS: 121 DAYS)

Parameter	Treatments		% Difference
	Surface Slope[a]		
	7.5%	15%	
Number of animals	36	36	
Daily gain	2.64	2.49	5.7
Feed consumption	20.94	20.50	2.1
Efficiency (feed/gain)	7.93	8.23	3.6
	Shading[a]		
	Covered	Open	
Number of animals	36	36	
Daily gain	2.57	2.56	
Feed consumption	20.79	20.65	
Efficiency (feed/gain)	8.09	8.07	
	Animal Density (square feet/animal)		
	30	120	
Number of animals	72	18	
Daily gain[b]	2.57	3.03	15.2
Feed consumption[c]	20.72	21.39	3.1
Efficiency (feed/gain)[b]	8.08	7.08	12.4

[a] No statistical treatment differences among parameters ($P < .05$).

[b] Statistically different ($P < .005$).

[c] Statistical difference at $P < .10$.

Results of Feeding Trials

Carcass measurements were taken on the animals in Experiments I and II. In both studies, no statistical differences ($P < .05$) were detected between treatments for the parameters which were monitored.

The increase of animal density to 40 square feet and 30 square feet per animal resulted in lowered daily gain and efficiency of feed utilization ($P < .005$). Feed consumption decreased with increasing density.

Solid Waste Accumulation on the feedlot surface was affected most by ration composition, Table 5. Feeding an all-concentrate finishing ration to feedlot cattle resulted in 2.3 pounds of dry waste accumulation per head daily. A 12 percent roughage finishing ration resulted in 5.0 pounds, and a 10 percent roughage ration resulted in 4.4 pounds of dry waste per animal per day. Both covering the feedlot and continuously wetting the open pen surface reduced dry waste accumulations.

TABLE 5. SOLID WASTE ACCUMULATION DURING THE FEEDING PERIODS

Item	Experiment I		Experiment II, 10% Roughage		
	All-concentrate	12% Roughage	Covered	Open	Continuously Wet
Number of animals	23	24	26	27	13
Feed dry matter, lb	60,768	77,110	60,430	64,229	30,723
Waste accumulation					
Total pounds	19,110	44,930	29,850	33,610	19,950
Dry matter %	47.0	46.9	48.2	49.0	44.0
Dry matter, lb	8,982	21,072	14,388	16,469	8,778
Feed:waste ratio, D.M. basis	6.8:1	3.7:1	4.2:1	3.9:1	3.5:1
Animal days	3,950	4,237	3,600	3,672	1,815
Square feet/animal	95	88	42	41	84
Live weight, lb	745	775	678	679	649
Daily dry matter waste accumulation					
Per head, lb	2.3	5.0	4.0	4.5	4.8
Per 100 lb live weight, lb	0.31	0.65	0.59	0.66	0.74
Per head per square ft, lb	0.024	0.057	0.10	0.10	0.057

Of the other treatment variables studied in separate feeding experiments involving 7-1/2 percent slope versus 15 percent slope in concrete pens, open versus covered pens, dirt versus concrete pen surfaces, and continuously clean versus continuously wet concrete surfaces, none of the comparisons resulted in statistically significant differences in animal performance, although tendencies might be observed as shown by the data in Tables 2, 3, and 4.

Runoff From Concrete-Surfaced Feedlots

The precipitation regime during the experimental period in Lubbock, Texas was typical of the area. Very little precipitation occurred during the winter months, approximately 8 inches occurred during the spring of 1969 and very little occurred during the summer. A near record 18 inches of rain fell during the fall of 1969. Very little rain fell again during the winter of 1969-1970, and the total rainfall for all of 1970 was only 9 inches. Almost half of this rain occurred during the tornado of May 11, 1970.

A manual type rain gage was located in the vicinity of the feedlots to determine the total precipitation for each event. No attempt was made to establish the rate of precipitation. The total quantity of runoff from the lots was measured by noting the change in elevation of the liquid level in the pits before and after the period of precipitation and calculating the total volumetric change as a function of the difference in liquid level.

Samples of accumulated runoff were taken from the collection ponds on a weekly basis for analysis. In addition, a number of grab samples of runoff were taken at 30-minute intervals during runoff-producing rainfalls. Later, an automatic sampler was installed to collect samples at 15-minute intervals from one of the lots, but very little runoff occurred after it was installed.

Rainfall-runoff relationships were found to be influenced by type of ration fed. The fraction of incident precipitation running off feedlots on which all-concentrate rations were fed was greater than the fraction running off lots on which 12 percent roughage ration were fed. Typical data obtained from lots on which all-concentrate rations were fed are given in Table 6.

TABLE 6. TOTAL PRECIPITATION AND RUNOFF FROM CONCRETE-SURFACED FEEDLOTS FROM AUGUST 20, 1969 THROUGH OCTOBER 21, 1969. ALL-CONCENTRATE RATION WAS FED DURING THIS PERIOD

Date	Rainfall In.	Retention In.	Runoff In.	Runoff Percent
8-20-69	0.09	0.09	0	0
8-24-69	1.40	0.727	0.673	48.00
8-25-69	2.29	0.58	1.710	74.60
8-27-69	0.40	0.185	0.215	53.80
8-28-69	0.29	0.246	0.044	15.20
9-08-69	0.20	0.20	0.00	0
9-09-69	1.01	0.398	0.612	60.60
9-10-69	0.23	0.23	0.00	0
9-13-69	1.38	0.806	0.573	41.50
9-17-69	2.72	0.572	2.15	79.00
9-21-69	1.08	0.302	0.778	72.00
9-22-69	0.83	0.488	0.342	41.30
10-6-69	0.43	0.427	0.003	0.67
10-19-69	0.04	0.04	0.00	0
10-21-69	2.86	0.96	1.90	66.50
10-22-69	1.64	0.754	0.386	54.00
10-23-69	1.45	0.904	0.546	37.70
Total	18.34	8.308	10.032	56.50

Analysis of all data obtained from these lots yielded the relationship shown in Figure 2.

Typical data derived from identical lots on which a 12 percent roughage ration was fed are presented in Table 7.

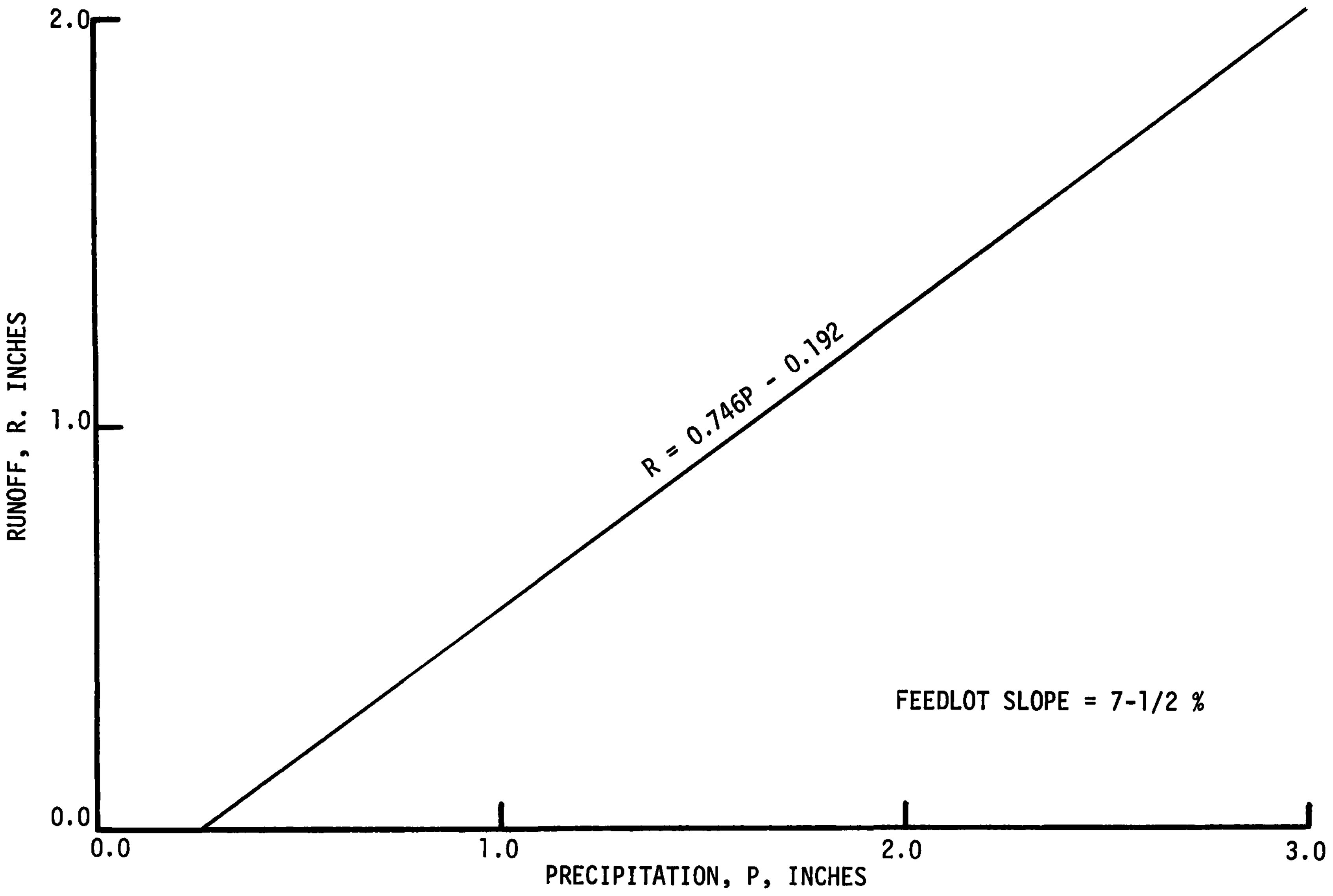

FIGURE 2. PRECIPITATION-RUNOFF RELATIONSHIP FOR CONCRETE-SURFACED FEEDLOTS ON WHICH ALL-CONCENTRATE RATIONS WERE FED.

The feed pens from which the data presented in Tables 6 and 7 were derived were identical; each contained the same number of cattle of the same size, each was thoroughly cleaned before the experiment started, and each was stocked with cattle on the same day. The only known variable in the experiment was the ration. One group of cattle was fed an all-concentrate ration and the other was fed a ration containing 12 percent roughage.

TABLE 7. TOTAL PRECIPITATION AND RUNOFF FROM CONCRETE-SURFACED FEEDLOTS FROM AUGUST 20, 1969 THROUGH OCTOBER 21, 1969. TWELVE PERCENT ROUGHAGE RATION WAS FED DURING THIS PERIOD

Date	Rainfall In.	Retention In.	Runoff In.	Runoff Diff Percent
8-20-69	0.09	0.09	0.00	0
8-24-69	1.40	0.835	0.565	40.03
8-25-69	2.29	0.975	1.315	57.50
8-27-69	0.40	0.40	0.00	0
8-28-69	0.29	0.29	0.00	0
9-08-69	0.20	0.20	0.00	0
9-09-69	1.01	0.538	0.472	46.80
9-10-69	0.23	0.23	0.00	0
9-13-69	1.38	0.821	0.559	40.50
9-17-69	2.72	0.394	2.32	85.40
9-21-69	1.08	0.625	0.455	42.00
9-22-69	0.83	0.582	0.248	30.00
10-6-69	0.43	0.430	0.00	0
10-19-69	0.04	0.040	0.00	0
10-21-69	2.86	1.400	1.460	51.00
10-22-69	1.64	1.125	0.515	31.40
10-23-69	1.45	1.368	0.082	0.57
Total	18.34	10.448	7.891	43.00

The analysis of all runoff data collected from the lot on which the roughage-concentrate ration was fed yielded the relationship shown in Figure 3.

As noted previously, the quantity of solid waste accumulating in the lot on which a roughage-concentrate ration was fed was more than twice as great as the quantity accumulating in the other lot. Differences in retention rates were attributed to the depth of manure available for storing water, to a difference in water holding capacity of the wastes resulting from the two types of feed materials, or to a combination of these and other factors.

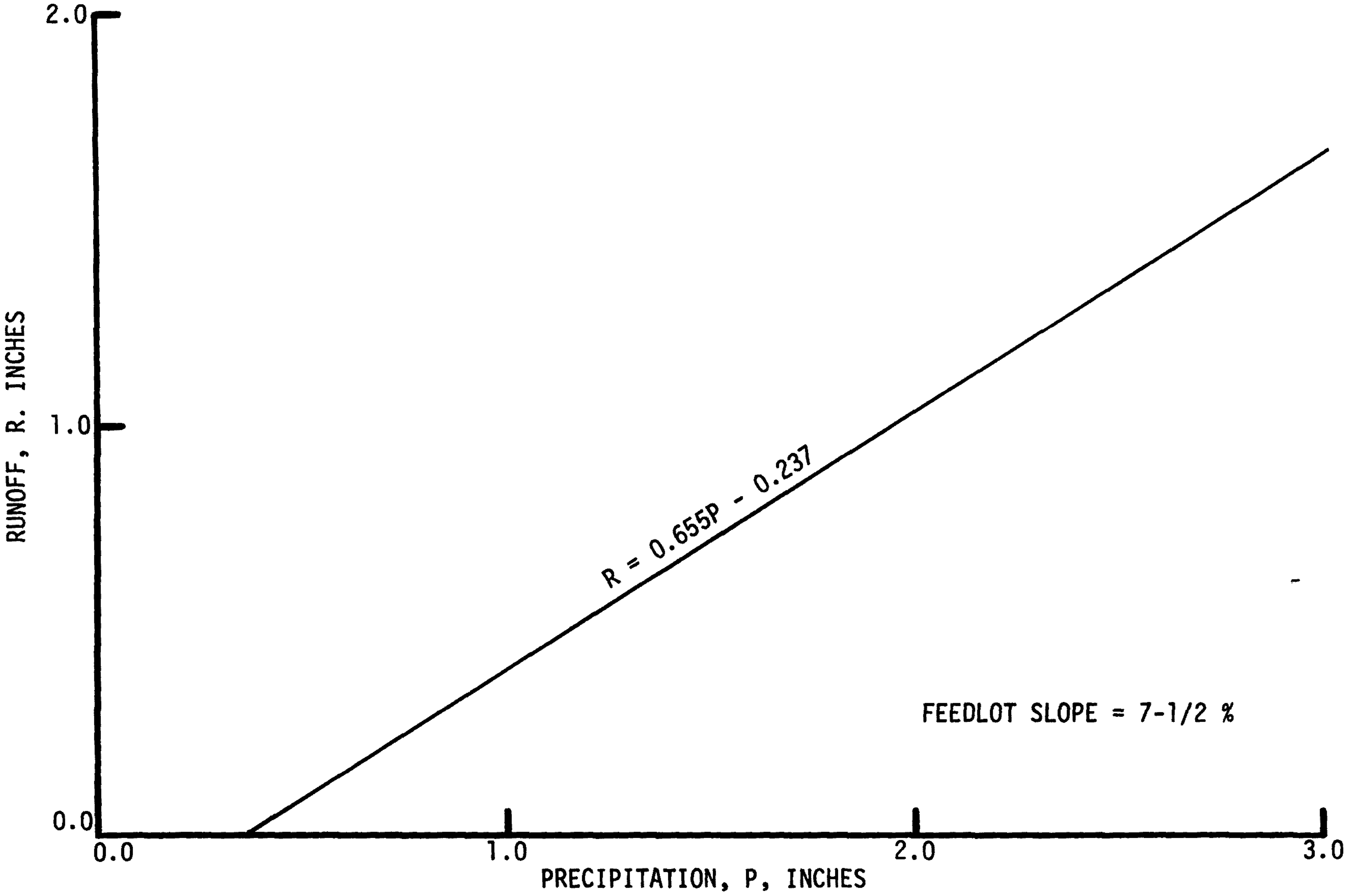

FIGURE 3. PRECIPITATION-RUNOFF RELATIONSHIP FOR CONCRETE-SURFACED FEEDLOTS ON WHICH 12 PERCENT ROUGHAGE RATIONS WERE FED.

Quality and Quantity Relationships

Grab samples of runoff were collected from each pair of lots at approximately 30-minute intervals during each of several runoff-producing precipitation events. Analyses of a typical set of runoff samples collected from concrete surfaced lots during a storm of August 24, 1969, are presented in Table 8.

TABLE 8. CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM CONCRETE LOT RESULTING FROM PRECIPITATION STARTING AT 11:00 P.M. ON AUGUST 24, 1969

Time of Collection	pH	BOD (mg/l)	COD (mg/l)	NO_3 (mg/l)	NH_3-N (mg/l)	ORG-N (mg/l)	ALKY (mg/l)
11:35 p.m.	6.60	16,800	48,000	625	525	532	2595
11:58 p.m.	6.80	6,120	20,451	975	526	315	1955
12:35 a.m.	6.65	7,400	22,032	1000	485	36	2000
2:25 a.m.	6.80	9,950	23,316	900	543	285	1865

These data indicate that the initial runoff contains a higher concentration of pollutants, particularly BOD and COD, than does subsequent runoff. This difference is not considered to be significant since the quality of runoff remains very poor, regardless of the duration of the runoff. This observation was duplicated repeatedly in samples taken from feedlots while runoff was occurring and experiments utilizing a tilting table to stimulate a feedlot in the laboratory.

The effects of rations on runoff quality are indicated by data presented in Tables 9 and 10. Values shown in these tables are averages of several grab samples collected from each lot while runoff was occurring.

TABLE 9. CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM CONCRETE-SURFACED LOT ON WHICH CATTLE WERE FED ALL-CONCENTRATE RATION

Date	pH	BOD (mg/l)	COD (mg/l)	NO_3 (mg/l)	NH_3-N (mg/l)	ORG-N (mg/l)	ALKY (mg/l)
8-24-69	6.30	7,355	28,929	1270	340	610	1030
8-26-69	5.90	8,900	38,400	280	395	302	1584
9-9-69	5.60	10,400	30,230	228	518	797	1174
9-22-69	6.90	4,424	10,080	36	460	650	1380
10-21-69	6.35	8,300	20,742	386	304	293	116
10-26-69	6.70	12,000	23,000	350	140	235	236
11-1-69	7.30	2,395	4,971	0	120	250	116

TABLE 10. CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM CONCRETE-SURFACED LOT ON WHICH CATTLE WERE FED ROUGHAGE-CONCENTRATE RATION

Date	pH	BOD (mg/l)	COD (mg/l)	NO_3 (mg/l)	NH_3-N (mg/l)	ORG-N (mg/l)	ALKY (mg/l)
8-24-69	6.70	10,067	28,450	875	519	300	2104
8-26-69	6.15	8,500	32,800	320	515	384	2056
9-9-69	6.62	12,750	32,172	97	774	301	2402
9-22-69	6.75	5,270	11,514	22	100	132	1632
10-21-69	6.67	10,250	20,868	140	406	114	170
10-26-69	6.85	3,300	8,400	70	33	35	86
11-1-69	7.00	5,566	16,252	0	115	115	336

The concentrations of pollutants in runoff are relatively independent of the type of ration fed as shown in the above two tables. It is worth noting, however, that if the concentrations were identical, the total quantity of pollutants contained in runoff from lots on which all-concentrate rations were fed would exceed by about 25 percent the quantity contained in runoff from lots on which roughage-concentrate rations were fed because of the increased volume of runoff.

Effect of Slope on Waste Movement

The eastern most halves of Lots 1 and 4 (Figure 1) were modified to a slope of 15 percent, double the 7-1/2 percent slope of the original lots. At this time, Lot 1 had been equipped with a sheet iron roof. The other steep sloped lot was uncovered.

Cattle were placed in all four lots at equal population densities and fed for 150 days. No difference in animal performance was noted as a result of slope during the feeding period, Table 4. The increased slope affected the movement and final deposition of the waste on the feedlot surface. On both the covered and uncovered treatments the waste movement on the 15 percent slope toward the lower-edge of the slope resulted in less than one inch of waste accumulation on the upper two-thirds of the lot surface. This was in marked contrast to the shallower slope where waste movement by action of the animals was less complete and several inches accumulated on the upper surface.

The fencing along the lower edge of the lot restricted the movement of the waste from the lot. As a result a considerable depth of manure accumulated on the fence line and prevented further movement of the waste material. Modifications in the shape and slope of the surface are indicated to remove this blockage. A slotted floor along the lower edge or a fence design with sufficient clearance between the lot surface and the lower edge of the fence might facilitate the movement of the waste out of the animal area.

STUDIES WITH DIRT-SURFACED FEEDLOTS

Two dirt-surfaced feedlots, each measuring 80 by 100 feet and sloped at 2-1/2 percent in a northwesterly direction along the long dimension were used in conducting the study. The lots were surfaced with caliche obtained locally and were graded to a uniform slope at the beginning of the experiment.

Each lot drained into a separate collection pit immediately adjacent to the lower end of the lot, Figure 4. Instrumentation was installed to measure pit volume, to allow for sampling during periods of runoff, and to measure total precipitation.

Animal Feeding Studies

One feeding trial lasting 173 days was conducted on dirt-surfaced lots to compare animal performance on concrete and dirt-surfaced lots. However, the dirt-surfaced lots shown in Figure 4 contained cattle throughout the period of the project and samples of runoff were routinely collected from these lots along with the collections from the concrete lots.

The all-concentrate and 12 percent roughage rations shown in Table 1 were fed to 28 steers each in Lots 1 and 2, Figure 4 respectively.

The mean feedlot performance of steers on the dirt lots did not differ significantly from the performance of the steers on the concrete feedlot, Table 11.

It should be noted, however, that the feed/gain efficiency appeared to be somewhat better for steers on dirt lots than for those on concrete lots.

TABLE 11. MEAN FEEDLOT PERFORMANCE OF STEERS IN EXPERIMENT I (POUNDS: 173 DAYS)[a]

	Treatments		% Difference
	Dirt	Concrete	
Number of steers	55	47	
Daily gain	2.53	2.55	
Feed consumption	17.6	19.7	10.7
Efficiency (feed/gain)	6.93	7.54	8.1

[a] No statistical differences among the parameters ($P < .05$).

Because of the mixing of manure with the top surface of soil in a dirt-surfaced feedlot, it was felt that any attempt to measure the

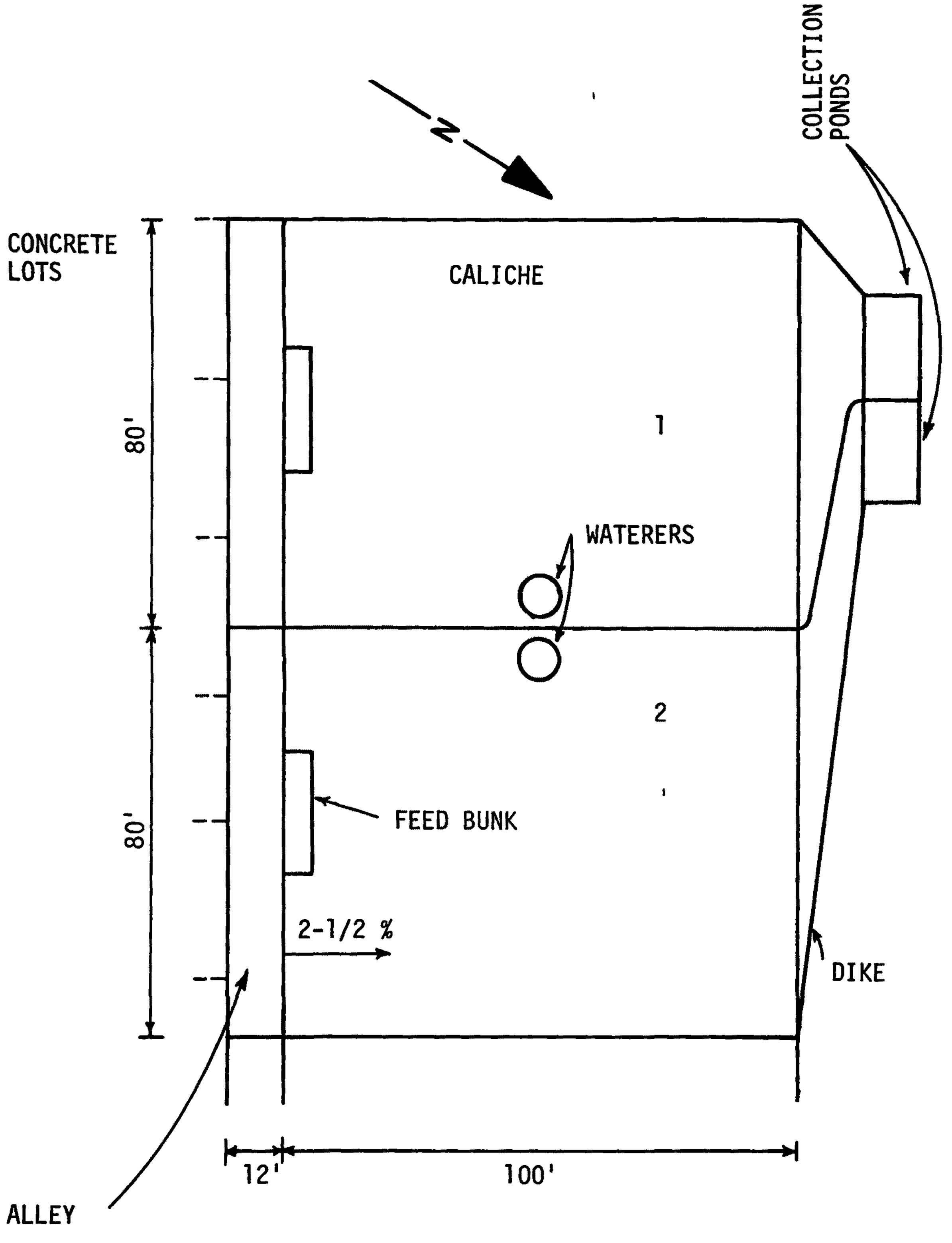

FIGURE 4. LAYOUT OF DIRT-SURFACED FEEDLOTS USED ON PROJECT.

quantity of solid waste accumulating on the dirt feedlot floor during one feeding trial would be futile. Therefore, no attempt was made to measure the total quantity of solid waste that accumulated on this surface. It is reasonable to assume, however, that on a long term basis, the quantity to be removed would be very nearly the same as the quantity to be removed from a concrete-surfaced lot.

Runoff From Dirt-Surfaced Feedlots

The method previously described for measuring runoff from concrete-surfaced feedlots was also used in determining the quantity of runoff from dirt-surfaced lots. Dirt-surfaced lots retained a higher fraction of incident rainfall than concrete-surfaced lots, and this phenomenon appeared to be relatively independent of the depth of manure contained on the lots.

Rainfall and runoff occurring during the same period in the fall of 1969 for which runoff data related to concrete-surfaced lots were presented in Tables 9 and 10 are shown in Tables 12 and 13.

TABLE 12. TOTAL PRECIPITATION AND RUNOFF FROM DIRT-SURFACED FEEDLOT FROM AUGUST 20, 1969 THROUGH OCTOBER 21, 1969. ALL-CONCENTRATE RATION WAS FED DURING THIS PERIOD

Date	Rainfall In.	Retention In.	Runoff In.	Runoff Percent
8-20-69	0.09	0.09	0.0	0
8-24-69	1.40	0.719	0.681	48.7
8-25-69	2.29	1.87	0.42	18.3
8-27-69	0.40	0.398	0.002	0.5
8-28-69	0.29	0.268	0.022	7.58
9-08-69	0.20	0.20	0.00	0
9-09-69	1.01	0.421	0.589	58.4
9-10-69	0.23	0.23	0.00	0
9-13-69	1.38	0.93	0.45	32.6
9-17-69	2.72	2.08	0.64	23.5
9-21-69	1.08	0.778	0.248	27.6
9-22-69	0.83	0.318	0.512	61.7
10-6-69	0.43	0.187	0.243	56.5
10-19-69	0.04	0.04	0.00	0
10-21-69	2.86	1.975	0.885	31.0
Total	18.34	13.598	4.742	25.8

Since the type of ration fed made no significant difference in the rainfall-runoff relationship for dirt-surfaced lots, all data obtained from these lots were combined to derive the relationship shown in Figure 5.

TABLE 13. TOTAL PRECIPITATION AND RUNOFF FROM DIRT-SURFACED FEEDLOT FROM AUGUST 20, 1969 THROUGH OCTOBER 21, 1969. TWELVE PERCENT ROUGHAGE RATION WAS FED DURING THIS PERIOD

Date	Rainfall In.	Retention In.	Runoff In.	Runoff Percent
8-20-69	0.09	0.09	0.0	0
8-24-69	1.40	0.839	0.561	40.00
8-25-69	2.29	1.87	0.423	18.50
8-27-69	0.40	0.398	0.002	4.50
8-28-69	0.29	0.269	0.021	7.25
9-08-69	0.20	0.20	0.00	0
9-09-69	1.01	0.476	0.534	50.28
9-10-69	0.23	0.23	0.00	0
9-13-69	1.38	1.12	0.26	18.80
9-17-69	2.72	2.11	0.61	22.40
9-21-69	1.08	0.514	0.566	52.40
9-22-69	0.83	0.365	0.465	56.00
10-6-69	0.43	0.43	0.00	0
10-19-69	0.04	0.04	0.00	0
10-21-69	2.86	2.064	0.796	27.80
Total	18.34	14.102	4.238	23.10

Additional comparative data obtained in the spring of 1969 are presented in Table 14.

TABLE 14. TOTAL PRECIPITATION AND RUNOFF FROM CONCRETE AND DIRT-SURFACED FEEDLOTS FOR THE PERIOD APRIL 11, 1969 THROUGH JUNE 13, 1969

		Concrete Lots 7-1/2 Percent Slope		Dirt Lots 2-1/2 Percent Slope	
Date	Total Rainfall In.	Retained In.	Runoff In.	Retained In.	Runoff In.
4-11-69	0.99	0.29	0.70	0.87	0.12
4-12-69	0.62	0.39	0.23	0.55	0.07
5-2-4-69	1.50	0.37	1.13	1.15	0.35
5-5-69	1.59	0.45	1.14	1.04	0.55
5-6-69	0.45	0.33	0.12	0.45	0
5-28-69	2.14	0.38	1.76	2.08	0.06
6-13-69	1.87	0.41	1.46	1.72	0.15

The capacity of the dirt lots to retain rainfall was much more variable than that of the concrete lots. The dirt feedlots retained approximately three times as much rainfall during the spring as did

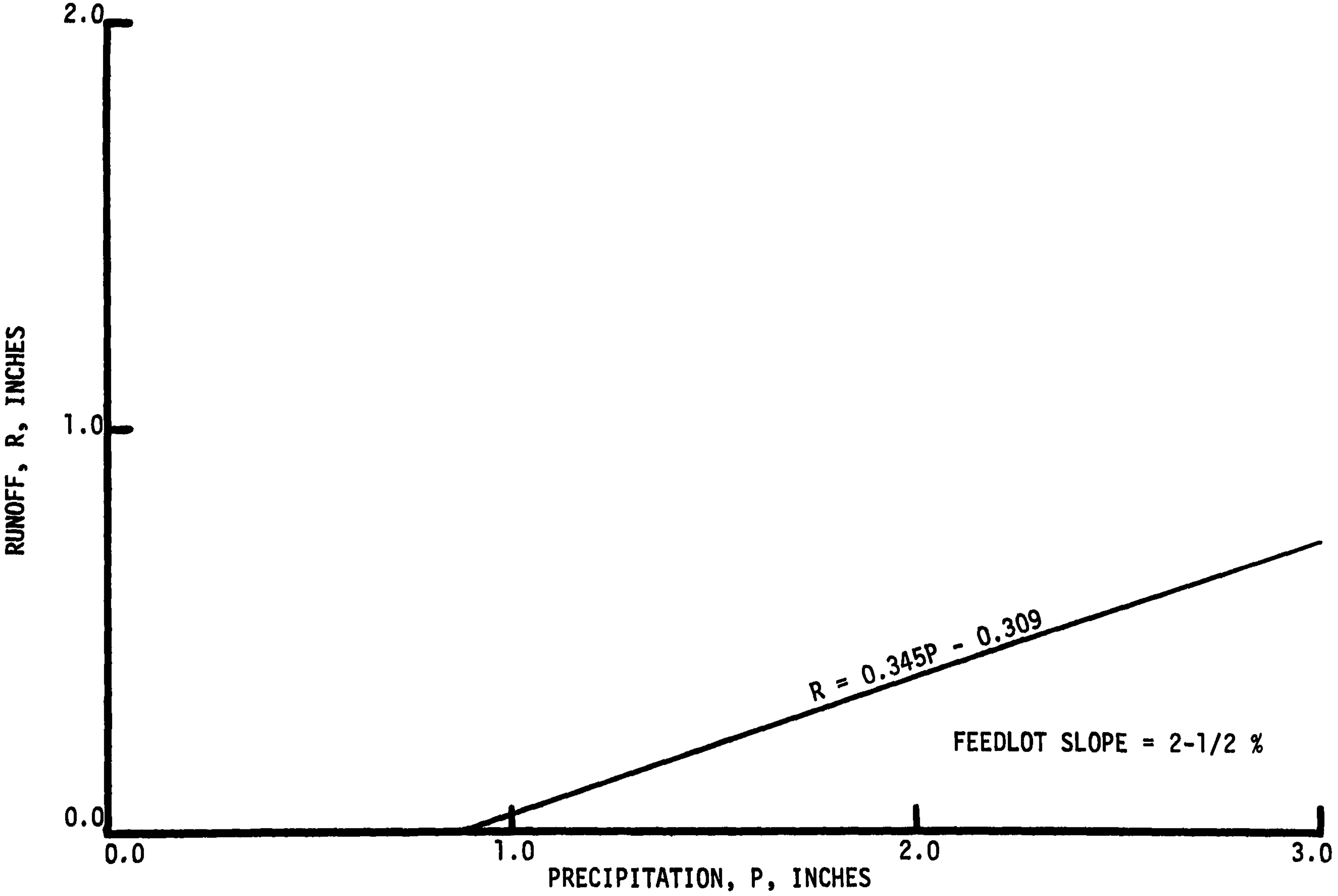

FIGURE 5. PRECIPITATION-RUNOFF RELATIONSHIP FOR DIRT-SURFACED FEEDLOTS.

the concrete feedlot. However, this difference was considerably less during the fall when both the waste and the soil contained high moisture concentrations due to the near-record rains recorded for this period.

Quality and Quantity Relationships

Grab samples of runoff were collected from each pen at approximately 30-minute intervals during several rainstorms. These samples were taken both during the 173 day feeding trial referred to earlier, and subsequently when the cattle in both pens were being fed 10 percent roughage rations. Typical results of analyses of a set of grab samples are shown in Table 15. It will be noted that the concentrations of pollutants shown in Table 15 are much less than the concentrations shown in corresponding Table 8.

TABLE 15. CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM DIRT LOT RESULTING FROM PRECIPITATION STARTING AT 11:00 P.M. ON AUGUST 24, 1969

Time of Collection	pH	BOD (mg/l)	COD (mg/l)	NO_3 (mg/l)	NH_3-N (mg/l)	ORG-N (mg/l)	ALKY (mg/l)
11:35 p.m.	7.80	1,630	5,450	16	51	27	1002
11:58 p.m.	7.50	2,500	9,781	128	98	297	1092
12:35 a.m.	7.60	1,275	6,240	132	100	434	1238
2:25 a.m.	7.80	1,630	11,650	136	67	44	1620

Tables 16 and 17 show the average concentrations of pollutants in grab samples taken at 30-minute intervals from the dirt-surfaced lots in the fall of 1969.

TABLE 16. AVERAGE CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM DIRT LOT ON WHICH CATTLE WERE FED ALL-CONCENTRATE RATION

Date	pH	BOD (mg/l)	COD (mg/l)	NO_3 (mg/l)	NH_3-N (mg/l)	ORG-N (mg/l)	ALKY (mg/l)
8-24-69	7.95	1,400	5,160	163	48	118	955
8-26-69	7.15	1,350	7,212	96	48	33	1602
9-9-69	7.62	1,145	6,220	6	83	25	864
9-22-69	7.30	1,580	4,817	62	75	20	746
10-24-69	7.35	1,390	4,042	24	50	22	70
11-1-69	7.10	3,210	9,942	0	30	17	360

TABLE 17. AVERAGE CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM DIRT LOT ON WHICH CATTLE WERE FED ROUGHAGE-CONCENTRATE RATION

Date	pH	BOD (mg/l)	COD (mg/l)	NO_3 (mg/l)	NH_3-N (mg/l)	ORG-N (mg/l)	ALKY (mg/l)
8-24-69	7.68	1,758	8,280	103	79	200	1238
8-26-69	7.40	1,010	2,964	24	77	25	928
9-9-69	7.70	1,340	6,316	3	75	50	856
9-22-69	7.63	1,400	28,000	3	71	40	1400
10-21-69	7.50	1,620	4,400	28	85	67	99
10-26-69	7.45	1,100	8,000	0	2	6	183
11-1-69	7.70	2,200	8,795	0	3	117	436

The concentrations of organic pollutants in runoff from dirt-surfaced feedlots were only about 30 to 40 percent of the corresponding concentrations in runoff from concrete-surfaced lots. Also, on a unit area basis, all precipitation that occurred during the project resulted in about twice as much runoff from concrete-surfaced feedlots as from dirt-surfaced feedlots. On a unit area basis, the total quantity of organic pollutants contained in runoff from dirt-surfaced lots was therefore only about one-sixth as great as the quantity contained in concrete-feedlot runoff.

Interpretation of Results

The above discussion appears to indicate that dirt-surfaced feedlots have a clear advantage over concrete-surfaced lots from the standpoint of prevention of water pollution. This is not necessarily true. Stocking rates normally used on concrete-surfaced feedlots are about two and one-half or three times as great as the rates used on dirt-surfaced lots. Hence, the quantity of runoff per animal on concrete-surfaced lots can be expected to be about two-thirds as great as the quantity of runoff per animal on dirt-surfaced lots. Also, both the concentrations of pollutants in runoff and the erratic nature of the occurrence of runoff from Southwestern cattle feedlots mitigate against any type of conventional treatment and subsequent release to surface waters. Either evaporation of liquids or land disposal of liquid wastes are therefore the only alternatives presently available. For either of these systems, the concentrations of pollutants in the water are relatively unimportant.

Because of the lesser quantity of runoff generated per head of cattle on concrete-surfaced lots, it appears that dirt-surfaced feedlots may not be the optimum environment on which to feed cattle for slaughter.

STUDIES WITH MODIFIED ENVIRONMENT FEEDING FACILITIES

Controlled environment chambers were constructed to determine the effect of climatic conditions on the rate of gain of the cattle, quantity and quality of waste produced, feed utilization efficiency, and treatability of the waste.

Environmental Chamber

The chamber shown as 3, Figure 6, measured 12 by 12 feet in plan with a 7 foot ceiling height. Environmental parameters controlled were air temperature and humidity, ventilation rate, and light periodicity and intensity. Air temperature was held to 85° F ± 1°, and air moisture was maintained at 50 percent relative humidity ± 4 percent. A complete change of air in the chamber was provided every five minutes. The chambers were lighted 24 hours per day using two 100 watt bulbs. Metering devices were installed to measure the water consumed by the animals as well as that used for flushing. The concrete floors were sloped one-eighth inch per foot to a central floor drain.

Each chamber housed three steers having an initial average weight of 587 pounds each. The feed consisted of an all-concentrate ration with the composition shown in Table 1. Water was available to the animals at all times from automatic drinking cups.

The floor surface was hosed down on a daily basis using eight gallons of water per minute at 150 psi pressure. The total water used per day was between 40 and 48 gallons. On many occasions mechanical scraping of the floor preceded washing. All of the flushings flowed by gravity to a 55 gallon capacity sump as shown in Figures 6 and 7. The sump was located outside the building and contained a submergible sump pump.

Anaerobic Treatability Studies

A two stage digestion system with a capacity of 30 gallons per stage was set up adjacent to the controlled environment chamber. A schematic sketch of the anaerobic system is shown in Figure 7. Both stages of digestion were maintained at 97° F by means of electrical heating units side mounted in each digester. Each digester was mixed continuously by means of a small centrifugal pump. Gas production from each digester was continuously measured by means of a wet test meter. Samples of the gas in each stage were collected with gas tight syringes.

Operational Procedures. On a daily basis, when the chamber was being hosed down the sump pump B was piped such that the flushings were continuously circulated in the sump A. After the environmental chamber was cleaned, six gallons of digested liquor were withdrawn

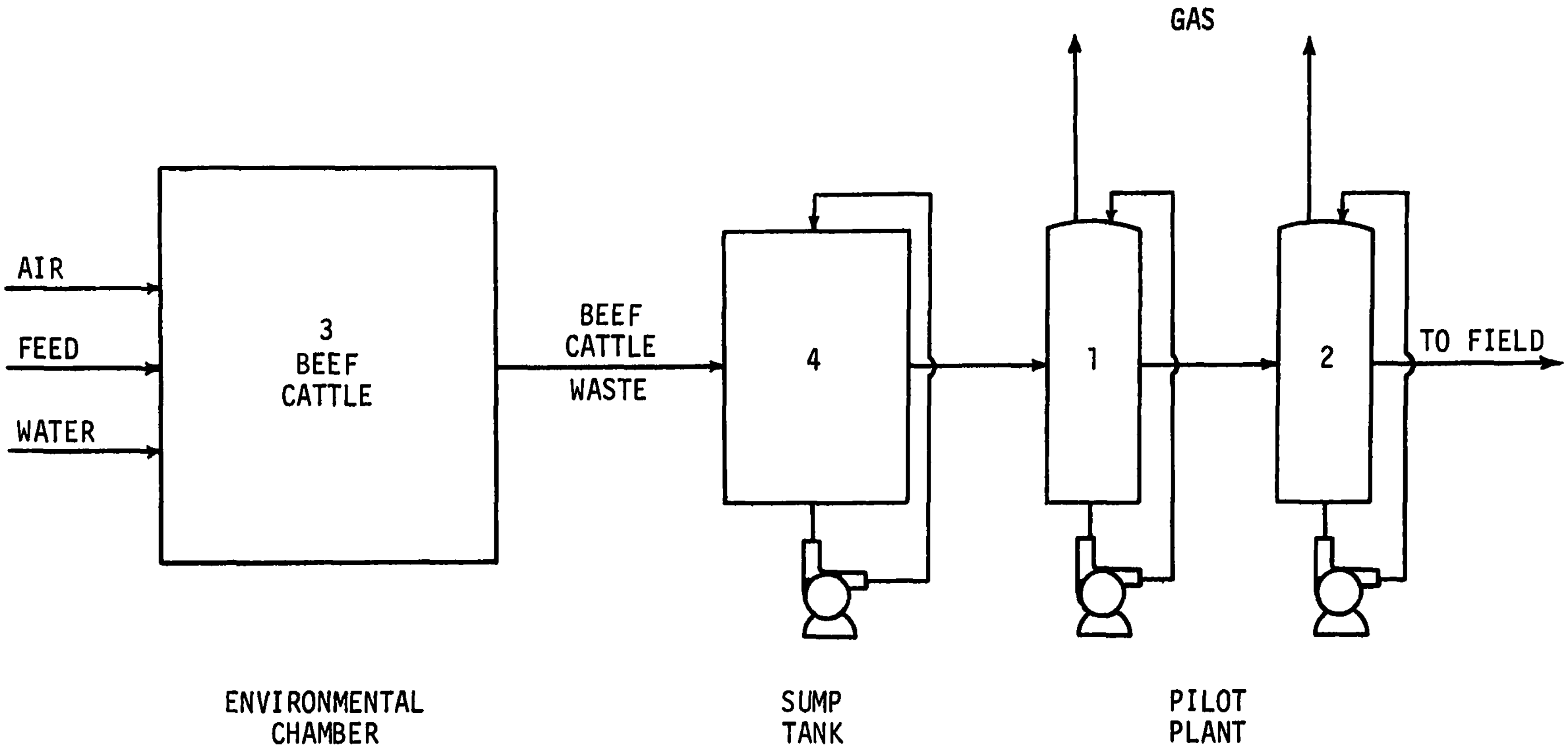

FIGURE 6. SCHEMATIC SKETCH SHOWING THE ENVIRONMENTAL CHAMBERS AND ASSOCIATED TREATMENT FACILITIES

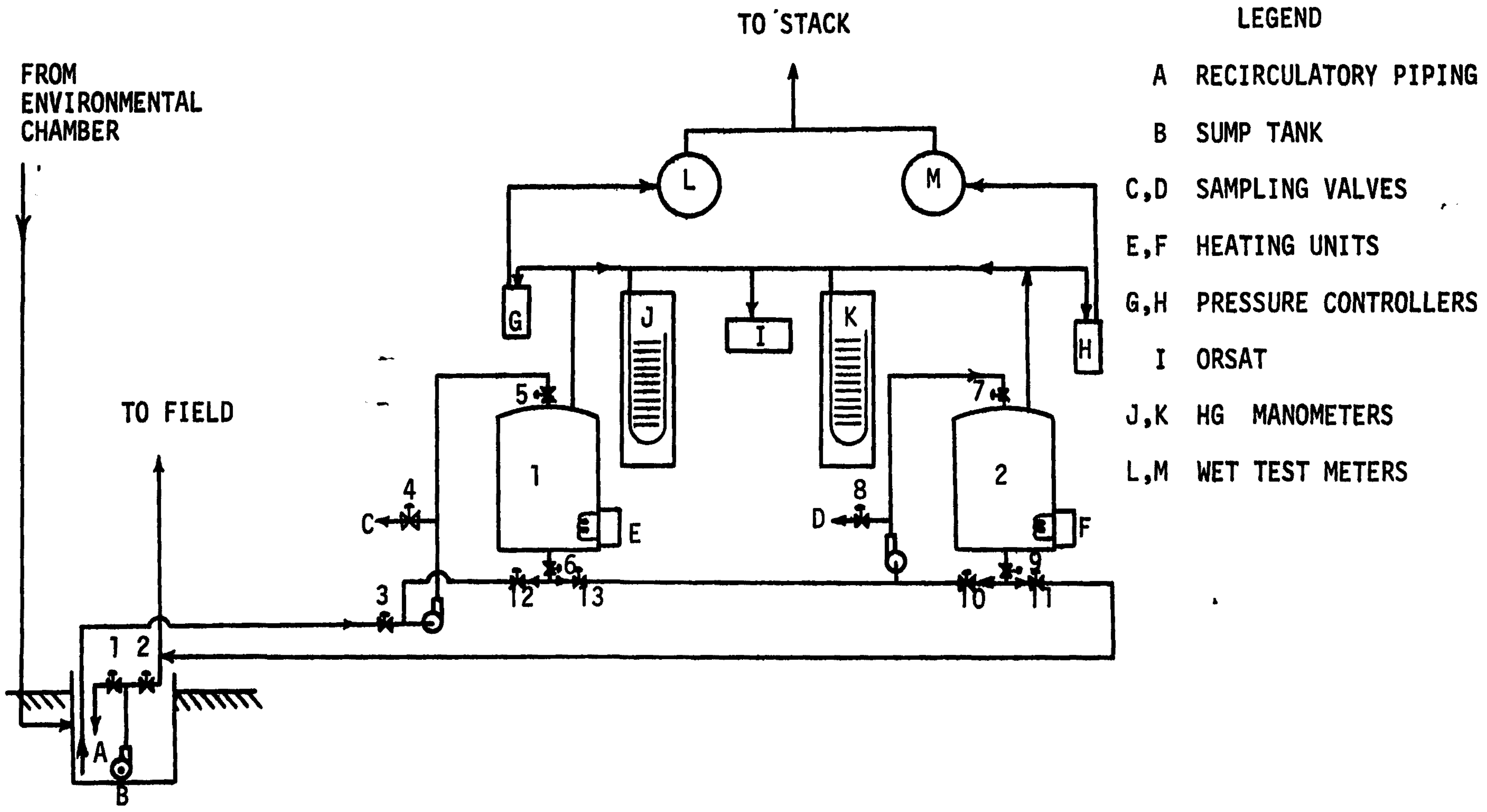

FIGURE 7. SCHEMATIC SKETCH OF THE ANAEROBIC DIGESTION PROCESS USED FOR CATTLE WASTE.

from Stage 2 and replaced with six gallons of effluent from Stage 1. Then Stage 1 was fed six gallons of completely mixed flushings. The pressure in each digester was controlled by means of a mercury manometer, G and H. The average pressure was 5.1 in. Hg.

Analyses. Gas samples were analyzed for methane and carbon dioxide content using an F & M Model 500 Gas Chromatograph. C-H-N analyses were conducted on a Model 185 Hewlett-Packard C-H-N Analyzer. The chemical and biochemical tests were performed in accordance with procedures outlined in "Standard Methods."

Seeding. Each digester was seeded initially with 30 gallons of digesting feedlot runoff collected from runoff pits adjacent to the cattle feedlots.

Objectives. There are two basic interrelated pollutional problems in each feedlot operation, namely, (a) the solid waste that accumulates on the feedlot floor and its periodic removal, and (b) the liquid runoff resulting from precipitation that must be treated and/or disposed of in a manner to prevent undue pollution of the environment. The primary purpose of this short term study was to determine the treatability of solid wastes from a modified environmental feeding facility housing three feeder steers using a two stage anaerobic digester. A summary of the average results obtained in this study are shown in Table 18.

Staged Digestion. Recent literature dealing with anaerobic digestion methods indicates considerable interest is now being given to utilization of a two step completely mixed digestion process in which the first stage allows the acid forming bacteria to produce such organic acids as acetic, propionic, etc., and the second stage promotes the methane producing bacteria which use these acids as a substrate.

BOD and COD Reduction. The mixed waste flushed from the floor of the environmental chamber using approximately 45 gallons of water per day had an average BOD concentration of 6500 mg/l and an average COD concentration of 13,000 mg/l. At the beginning of the experiment, when the average weight of the animals was 587 pounds each, the BOD production rate was approximately 0.8 pounds of BOD per animal per day. With the volume of washwater held constant, the concentration of BOD in the flushings increased with the size of the animals. The maximum rate of production of BOD was 0.9 pounds per animal per day when the animals weighed approximately 775 pounds each. Similarly, the COD concentration increased gradually with an increase in animal size ranging from 11,500 to 13,600 mg/l.

Under the operating conditions described, namely ten-day retention time, 97° F, and complete mixing, the average BOD and COD reductions were found to be 58 and 40 percent, respectively. It should also be noted that the majority of the BOD removal was obtained in Stage 2. Although these percent removals are not satisfactory in themselves as a means of standard treatment, it is felt that additional studies should continue especially in optimizing each stage for such removal.

TABLE 18. SUMMARY OF AVERAGE RESULTS OBTAINED FROM A COMPLETELY MIXED TWO STAGE DIGESTER WITH A CAPACITY OF 30 GALLONS PER STAGE, OPERATING AT 97° F AND A DAILY FEED RATE OF SIX GALLONS

Gas Production, Stage 1, STP	4.3 ft^3/day/ft^3 capacity
Stage 2, STP	2.82 ft^3/day/ft^3 capacity
CH_4, Stage 1, STP	53%
Stage 2, STP	72%
C:N, Feed	16.2
After 10 days digestion	9.4
pH, Feed	7.3
Stage 1	6.3
Stage 2	7.1
Volatile Acids, Stage 1	2,990 mg/l
Stage 2	1,030 mg/l
Alkalinity, Feed	2,100 mg/l
Stage 1	3,750 mg/l
Stage 2	4,700 mg/l
Average 5 day BOD, Feed	6,900 mg/l
After 10 days digestion	2,900 mg/l
Average COD, Feed	13,000 mg/l
After 10 days digestion	7,800 mg/l

Gas Production and Composition. The daily gas production at standard temperature and pressure (STP) per stage as a function of days of operation is shown in Figure 8. The average daily cubic feet of gas per cubic foot of capacity in Stage 1 was slightly more than two times that for Stage 2, namely 4.3 ft^3/ft^3 versus 2.8 ft^3/ft^3, respectively. Figure 9 shows that the average methane concentration in Stage 2 was 35 percent greater than in Stage 1, 72 percent versus 53 percent, respectively. These two values tend to give credence to the concept of an acid forming stage followed by a methane bacteria stage. The overall digestion process produced 5.7 ft^3 CH_4 per animal per day measured at standard conditions.

pH. Figure 10 shows the variation of pH in each stage during the 55 day period. It is interesting to note that the pH in each

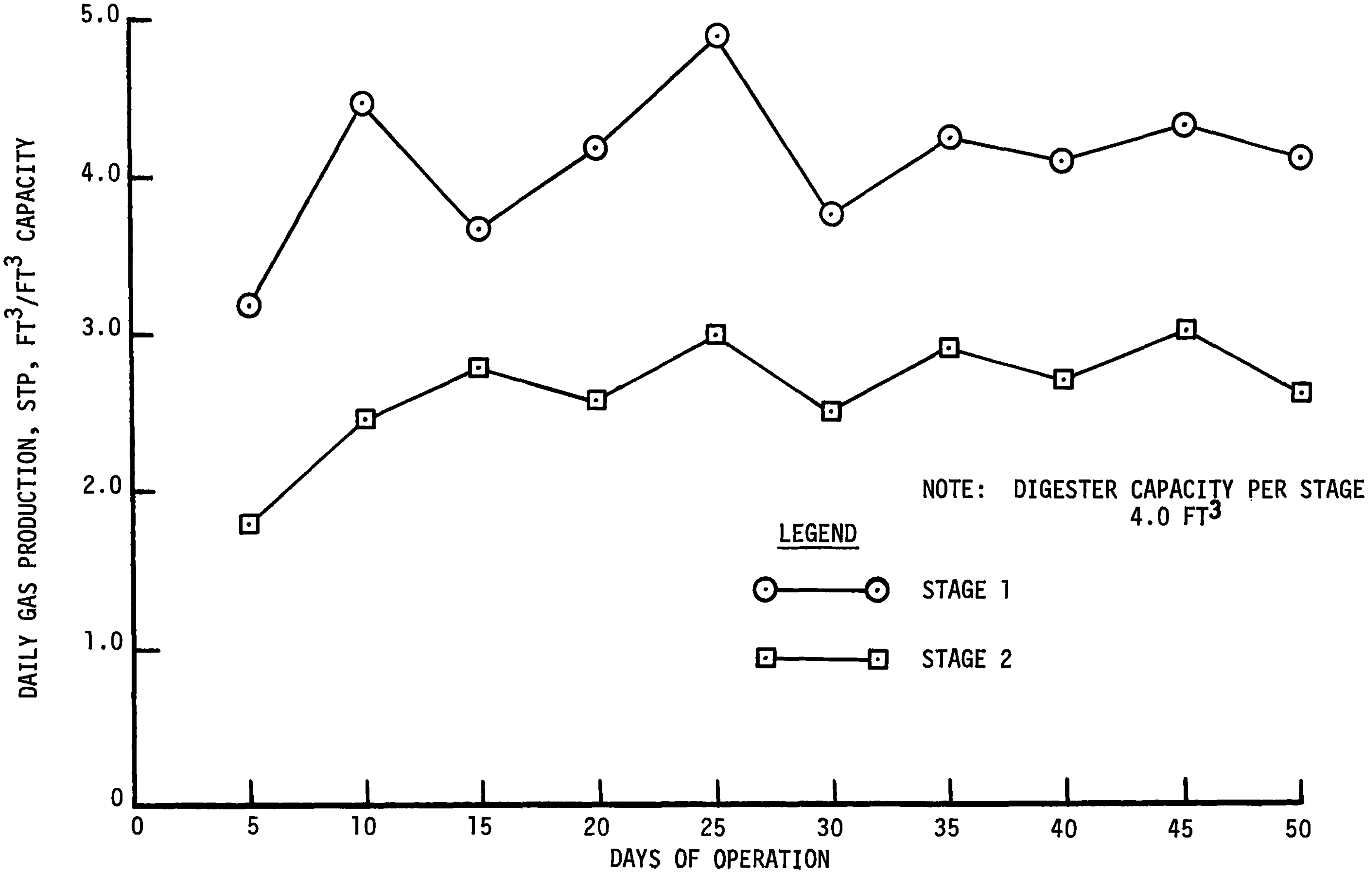

FIGURE 8. GAS PRODUCTION AS A FUNCTION OF TIME IN A TWO-STAGE ANAEROBIC DIGESTER.

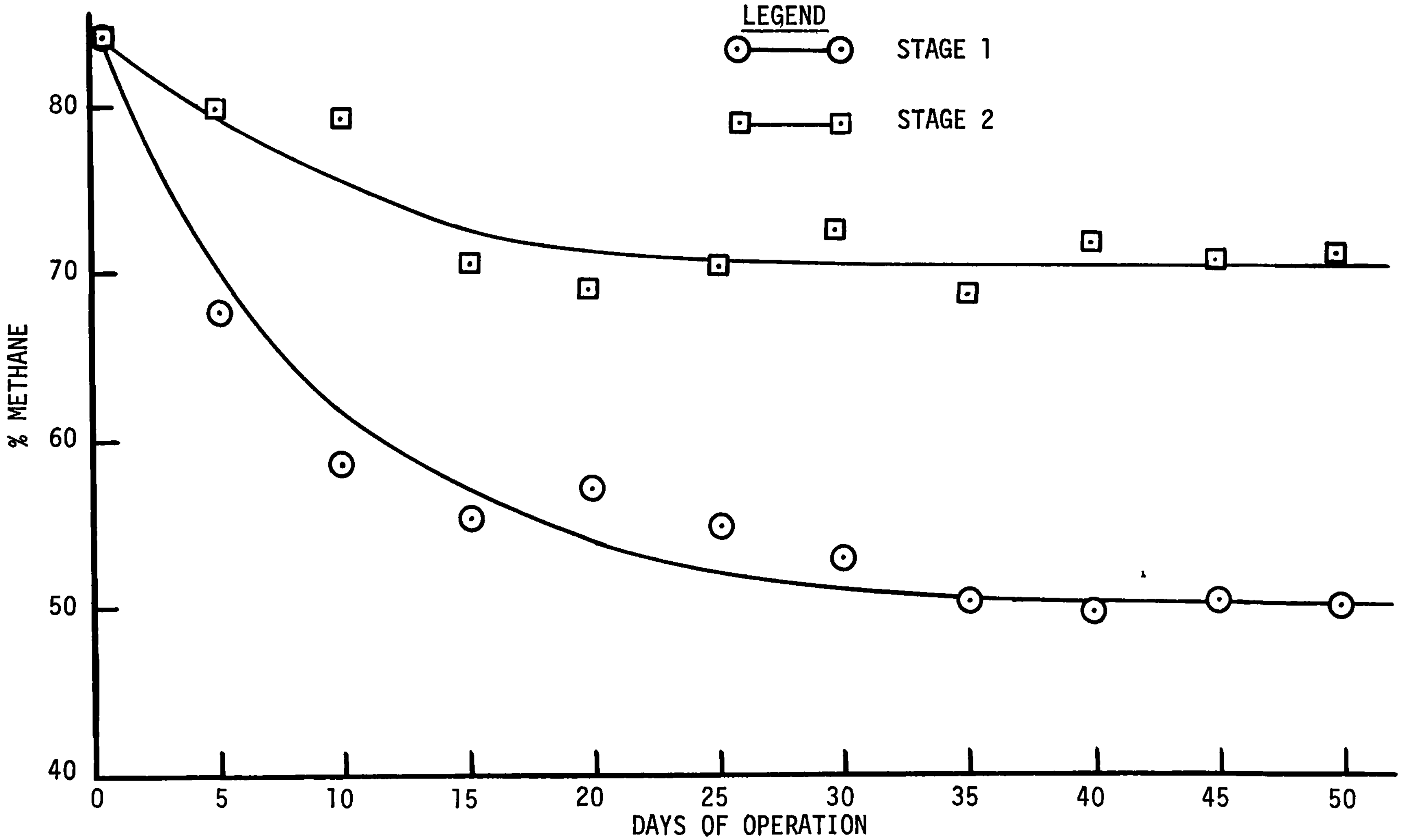

FIGURE 9. PERCENTAGE METHANE AS A FUNCTION OF TIME IN A TWO-STAGE ANAEROBIC DIGESTER.

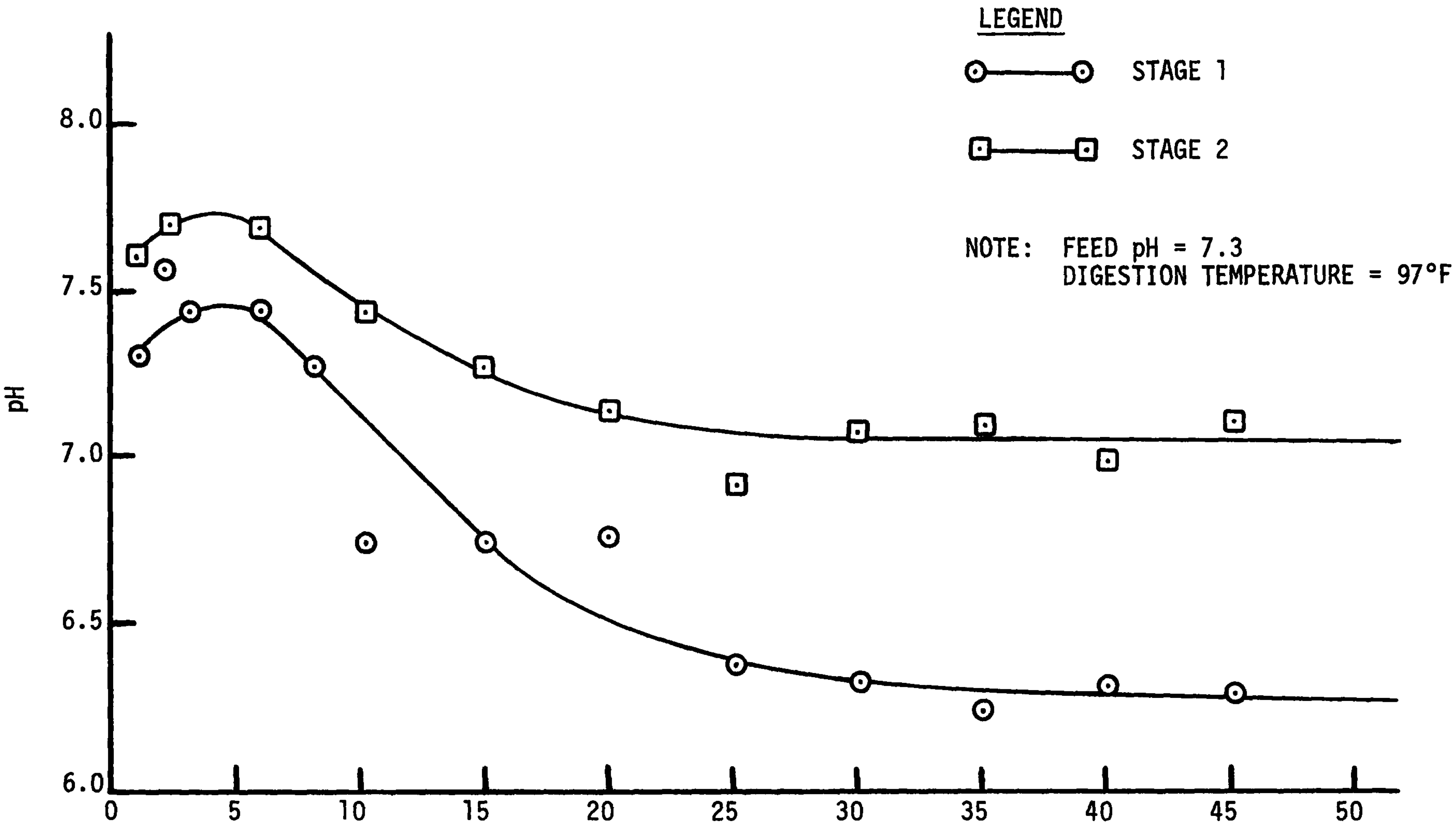

FIGURE 10. pH AS A FUNCTION OF TIME IN A TWO-STAGE ANAEROBIC DIGESTER.

stage remained relatively uniform after an acclimation period of approximately 20 days. No chemicals were added for pH control during the experiment. The average pH of Stage 1 was 6.3 whereas Stage 2 had an average pH of 7.1, indicating the possibility of an initial acid forming stage. The pH of the mixed flushings was 7.3, and it changed very little throughout the experiment.

Volatile Acids and Alkalinity. Figure 11 shows the relationship of volatile acids and alkalinity in each stage during the 55 day study. The specific interaction between volatile acids and alkalinity is not apparent from these data, although it can be noted that the alkalinity was always in excess of the volatile acid concentration. It is also interesting to note that the volatile acids concentration in Stage 1 was considerably higher than Stage 2, which is again indicative of an acid forming stage. The relatively high values of alkalinity come from the high carbonate content present in the all-concentrate ration shown in Table 1.

C-H-N Analyses. Several samples of the mixed flushings as well as the effluent from Stage 2 were analyzed for carbon, hydrogen, and nitrogen content. The average carbon to nitrogen ratio for the mixed flushings was 16.2 and the C:N ratio of the effluent was 9.2.

The carbon to nitrogen ratio of the feed indicated that this material is compostible. It should also be noted that there was a considerable amount of carbonaceous material remaining after ten days of digestion. The high COD values obtained for the effluent also substantiate this observation.

Aerobic Treatability Studies. Warburg Respirometer studies were conducted using flushings from the environmental chambers and runoff resulting from precipitation. The BOD of the flushings from the environmental chamber as determined by Warburg Respirometer studies averaged about 6,500 mg/l, about 15 percent more than the five day BOD as determined by the conventional dilution method.

The 37° C reaction rate constant for waste flushed from the controlled environment chamber was found to be very nearly 0.5 per day. This relatively high rate suggested that the wastes could be stabilized rather quickly by conventional aerobic treatment processes, but this did not prove to be the case in bench-scale laboratory studies.

Respirometer studies were also conducted using runoff resulting from precipitation on conventional feedlots. In general, the results obtained tended to be erratic and inconclusive. For example, total oxygen consumed in a 24-hour period tended to increase with increasing dilutions of the sample, indicating either that toxic or inhibitory elements were initially present in the waste or were produced by the microorganisms degrading the waste. This finding confirmed results of an experiment in which a bench-scale activated sludge unit

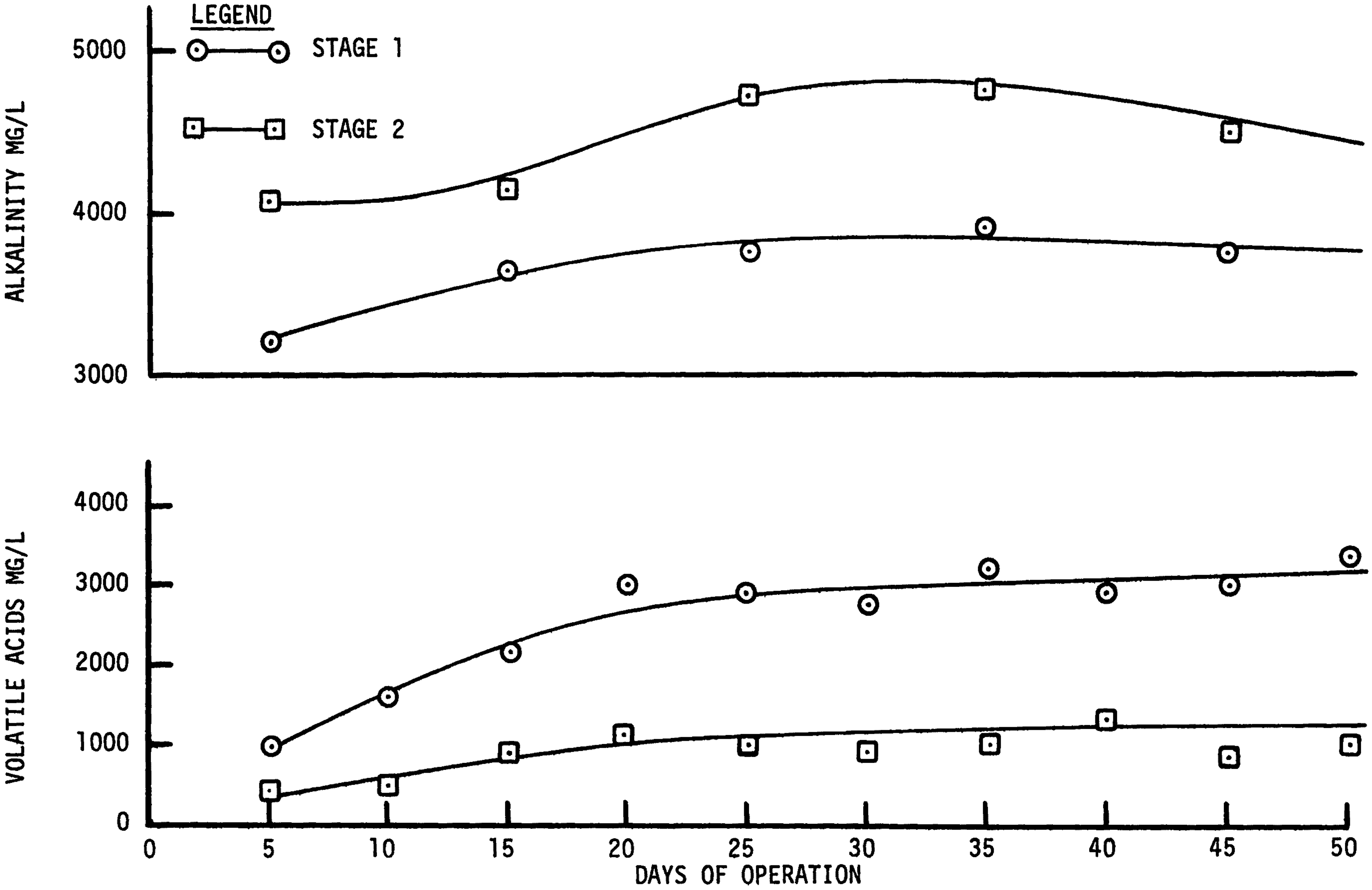

FIGURE 11. ALKALINITY AND VOLATILE ACIDS AS FUNCTIONS OF TIME IN A TWO-STAGE ANAEROBIC DIGESTER.

was utilized for treatment of similar runoff. In this experiment a 24-hour detention time in the unit resulted in a BOD reduction of only about 20 percent. Extended aeration studies of the waste at the conclusion of the experiment indicated that an extremely long aeration period of approximately 60 days would be required for effective stabilization of the waste.

LABORATORY SIMULATION STUDIES

Because of the extremely erratic nature of natural precipitation that occurs in the Southwest in general, a considerable amount of attention was devoted to characterization of feedlot runoff by laboratory simulations.

Two types of studies were performed. First, a series of 12-inch diameter plastic pipe cylinders were fitted with screens over the bottom ends. Samples of manure were placed in the cylinders, and water was sprinkled on the manure to determine the concentration of pollutants in leachates, and the variation of concentration with quantity of leachate. Second, a simulated feedlot surface in the form of a tilting table was constructed and equipped with a sprinkler system designed to apply simulated rainfall over a wide range of intensities.

Experiments with Percolation Cylinders

Several 12-inch diameter plastic pipe cylinders were equipped with screened openings on the lower end as described earlier. Arrangements were made for catching and measuring the quantity of water percolating through the cylinders, and a sprinkler device was designed to apply water to the cylinders at a uniform rate of one-inch per hour.

In-place density measurements of manure derived from all-concentrate, silage, and alfalfa hay-concentrate rations were then made. The quantity of manure required to provide two-inch, four-inch, and six-inch layers of manure in the 12-inch diameter cylinders were then calculated. Manure was collected at random from different feedlot surfaces and brought into the laboratory. Enough was weighed out in each case to provide either two, four, or six inches of manure in the cylinder, and this amount was placed in the cylinder and tamped down to the pre-determined density.

The sprinkler was then started and operated for several hours at an application rate of one-inch per hour. As water started percolating through the cylinder, it was separated into increments of one inch of percolated water. That is, the first inch percolating through the column was placed in one sample container, the second inch in another, and so on. Four inches of leachate were thus collected from each cylinder. Each sample was then analyzed to determine its concentration of total, volatile, and suspended solids, COD, BOD, ammonia nitrogen, nitrate nitrogen, organic nitrogen, and alkalinity. Some typical results derived from this experiment are shown in Tables 19 through 22.

Data in the above four tables corroborate and extend data gathered from the field in that they indicate that a very small depth of manure of the feedlot surface contains enough pollutants to pollute grossly any quantity of rainfall that is likely to occur. For example, the concentrations of pollutants contained in the first inch of

TABLE 19. CONCENTRATIONS OF COD IN WATER PERCOLATING THROUGH DEPTH OF MANURE IN COLUMNS AS SHOWN (mg/l)

Quantity of Leachate (in.)	Depth of Manure (in.)	Ration From Which Manure Derived		
		All-Concentrate	Alfalfa-Concentrate[1]	Silage[2]
1	2	27,000	13,600	5,000
2	2	15,800	8,300	2,300
3	2	10,200	6,700	980
4	2	3,800	4,900	200
1	4	21,200	14,900	7,900
2	4	18,500	11,600	4,700
3	4	15,800	9,100	2,700
4	4	13,700	8,400	980
1	6	22,800	19,200	7,500
2	6	21,600	14,300	5,700
3	6	21,100	12,000	10,500
4	6	21,800	9,400	2,800

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[1] Ration composition same as shown in Table 1, Experiment I, except that chopped alfalfa substituted for cottonseed hulls.

[2] Manure collected from feedlot on which cows were fed a maintenance ration consisting primarily of silage.

TABLE 20. CONCENTRATIONS OF VOLATILE SOLIDS IN WATER PERCOLATING THROUGH DEPTH OF MANURE IN COLUMNS AS SHOWN (mg/l)

Quantity of Leachate (in.)	Depth of Manure (in.)	Ration From Which Manure Derived		
		All-Concentrate	Alfalfa-Concentrate[1]	Silage[2]
1	2	21,300	13,400	4,400
2	2	14,400	4,700	1,600
3	2	12,200	3,500	1,050
4	2	-	3,100	750
1	4	23,400	2,700	5,500
2	4	17,700	9,100	2,900
3	4	14,200	5,500	1,950
4	4	12,800	6,600	1,300
1	6	29,500	12,000	6,100
2	6	22,700	11,300	3,500
3	6	20,700	11,400	8,200
4	6	26,600	8,900	2,900

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[1] Ration composition same as shown in Table 1, Experiment I, except that chopped alfalfa substituted for cottonseed hulls.

[2] Manure collected from feedlot on which cows were fed a maintenance ration consisting primarily of silage.

TABLE 21. CONCENTRATIONS OF ALKALINITY IN WATER PERCOLATING THROUGH DEPTH OF MANURE IN COLUMNS AS SHOWN (mg/l)

Quantity of Leachate (in.)	Depth of Manure (in.)	Ration From Which Manure Derived		
		All-Concentrate	Alfalfa-Concentrate[1]	Silage[2]
1	2	390	260	150
2	2	270	180	80
3	2	200	180	65
4	2	160	160	60
1	4	375	330	190
2	4	275	210	145
3	4	250	185	120
4	4	200	145	95
1	6	470	395	225
2	6	395	300	240
3	6	395	265	170
4	6	330	240	130

---

[1] Ration composition same as shown in Table 1, Experiment I, except that chopped alfalfa substituted for cottonseed hulls.

[2] Manure collected from feedlot on which cows were fed a maintenance ration consisting primarily of silage.

TABLE 22. CONCENTRATIONS OF AMMONIA NITROGEN IN WATER PERCOLATING THROUGH DEPTH OF MANURE IN COLUMNS AS SHOWN (mg/l)

Quantity of Leachate (in.)	Depth of Manure (in.)	Ration From Which Manure Derived		
		All-Concentrate	Alfalfa-Concentrate[1]	Silage[2]
1	2	1,200	745	34
2	2	880	525	19
3	2	700	415	11
4	2	400	310	75
1	4	1,170	840	45
2	4	1,000	670	13
3	4	870	585	24
4	4	750	535	24
1	6	1,350	1,100	40
2	6	1,270	835	40
3	6	1,380	710	560
4	6	1,190	595	30

---

[1] Ration composition same as shown in Table 1, Experiment I, except that chopped alfalfa substituted for cottonseed hulls.

[2] Manure collected from feedlot on which cows were fed a maintenance ration consisting primarily of silage.

water percolating through a quantity of manure were apparently independent of the total depth of manure. Also, the concentrations of pollutants contained in the first inch of water percolating through the manure agreed reasonably well with the average concentrations shown in Table 8. Most of these latter concentrations were average concentrations for less than one inch of runoff.

The above data make it apparent that, regardless of the quantity of runoff involved, far more than 99 percent of most pollutants would have to be removed from the runoff from normal feedlot operations before such runoff could be discharged to a water course without serious adverse effect on that water course. This is particularly true in the Southwestern region of the U. S. where existing water courses tend to be wet weather streams only.

Experiments with Tilting Table

A feedlot model measuring 12 ft by 4 ft was constructed. This box was mounted on a fulcrum to allow it to be tilted to any desired slope along the long dimension. One end of the table was slotted horizontally with one-half inch slots which extended the width of the table. These slots, fitted with covered half-round metal gutters were located 2, 6, and 18 inches below the top of the table. One-inch galvanized pipe was used to construct simple drains from each slot to calibrated vessels provided to capture the water running off. The end of the table away from the slots was equipped with a hydraulic jack which was used to vary the slope of the table and to support its heavy end.

A sprinkler system was installed approximately six feet above the table to provide simulated rainfall at any desired rate. The sprinkler system was equipped with a rotometer to measure accurately the rate of flow to the spray nozzles. The City of Lubbock water system served as the source of supply to the sprinklers.

The box provided a means for placing various depths of different types of soil and various depths of manure from any source in a simulated feedlot condition, then applying any desired rate of rainfall on any desired slope and collecting and analyzing the runoff from the surface, from the manure-soil interface, and from a reasonable distance below the manure soil interface. It was expected that the experiment would provide a valuable insight into the rate at which pollutants move downward through the soil zone, the effectiveness of the organic barrier that has been postulated by several investigators as a deterrent to percolation of water through a feedlot floor, and an indication of the effect of slope on runoff quality.

A mixture of top soil and caliche, similar to that used as a surfacing material on feedlots in the Texas High Plains, was used as a base material on the tilting table. Samples of in-situ feedlot surfacing materials were collected from feedlots on the Texas Tech campus to determine the apparent density. The quantity of base material required to fill the table to a depth of 12 inches was then calculated, weighed, and compacted onto the table.

The manure used for experimentation was collected from feedlots on which cattle were fed a ration identical to that shown in Table 1, Experiments II and III.

Manure was placed directly on the base material in a layer four inches thick for two runs, and two inches thick for the third run. The slope of the table was maintained at three percent for all three runs. The precipitation rate used for the first run was 1.5 inches per hour, and one inch per hour for the second and third runs. Runoff samples were collected every half hour over the one hour test period for the first run and over the first three hours of the second run. Subsequent samples on the second run were collected at four hour intervals for the last eight hours. Samples were collected at eight hour intervals for the third run. The length of the test period for the second run was 25.5 hours, and the length of the test period for the third run was 24 hours.

At the termination of each run, the manure and base material were examined for moisture content. Visual examination and moisture analyses were utilized for making these examinations.

Upon completion of the first series of runs, the caliche surface was cleared of manure and a two inch layer of commercial mortar sand was placed to form an interface or drainage layer between the caliche and the organic waste.

Two tests were then conducted using manure collected from the feedlots, in chunks, placed upon the sand. In the first of these runs, chunks of ten percent roughage manure six inches square, and two inches thick were placed to form a two inch layer of manure. The layer of manure, which was not compacted extensively, contained many small crevices. A feedlot slope of three percent was used in conjunction with a precipitation rate of one inch per hour. Runoff samples were collected at ten hour intervals over the 24 hour test period beginning four hours after start up. The surface runoff rate was measured at the end of the run. After the test period, samples of the subsurface manure were inspected visually.

For the next run, manure was collected from cattle on a dirt-surfaced feedlot where a ration containing 15 percent roughage was being fed. The chunks of manure, in approximately ten inch squares and one to six inches thick, were placed on the sand to form a manure layer one to six inches thick. Cracks in the manure layer, after limited compaction, varied in size from one inch down to small crevices. The feedlot slope used in this experiment was three percent, and the precipitation rate used was one inch per hour. Runoff samples were collected at seven hour intervals for the 22.5 hour test period. The surface runoff rate was measured at the end of the run. After the test period, the manure was inspected visually.

The eroded manure and standing water were removed following each run, and feedlot manure was added as needed to maintain a high moisture content in the manure and a non-eroded surface. Indentations were made in the manure surface before each run by manually pressing boots into the manure surface at random intervals. Precipitation rates tested were one, two, and three inches per hour. Feedlot slopes tested were one, three, six, and nine percent. The duration of each run at each slope and precipitation rate was two hours. The runoff rate was measured during each run to ascertain water losses and to check rotometer accuracy.

On each run, the first sample collected was the first runoff to appear. Thereafter, samples were collected at 50-minute intervals during the first hour for the one inch per hour precipitation rate. For the precipitation rates of two and three inches per hour, samples were collected every ten minutes for the first half hour. Samples were collected every half hour for the remaining 1.5 hours.

The data collected from the simulated feedlot runoff experiments were plotted on rectangular coordinates and a curve was visually fitted to the data points. Each of the analyzed characteristics was plotted against time with a maximum of three characteristics plotted per chart. These graphs were categorized and analyzed first for the effects of feedlot slope at each precipitation rate and then for the effects of precipitation rate at each feedlot slope.

Results

A feedlot slope of three percent and a precipitation rate of 1.5 inches per hour were used in making a one hour run. Only surface runoff occurred during the run. Visual inspection of subsurface manure and of base material after precipitation indicated a negligible amount of water had infiltrated through the manure.

Tests were then conducted on a feedlot slope of three percent and a precipitation rate of one inch per hour. The effects of manure depth and extended precipitation on water infiltration through the manure were studied during the first run of this test. The second run tested infiltration through four inches of manure for a 25.5 hour precipitation period. The third run of 24 hours tested infiltration through a two inch layer of manure. Before the second run, manure samples contained 54 percent moisture and before the third run, manure samples contained 55 percent moisture. Subsurface manure samples were collected at the termination of each run. Samples contained 55 percent moisture after the second run, and 57 percent moisture after the third run. Visual examination of the base material again indicated a negligible quantity of water had infiltrated through the manure.

The next two runs explored the effects of compaction and of roughage content of rations on infiltration rates. The manure applied to the table contained cracks and open spaces which penetrated the entire depth of the manure. At the end of each 24 hour run, during which only surface runoff occurred, the cracks and open spaces were sealed with manure. The surface runoff rate was measured at the end of the run and in both cases it equaled the precipitation rate. Again, visual inspection of the manure indicated that a negligible quantity of water had infiltrated through the manure pack.

The testing procedure was continued through a total of 12 runs over a period of approximately three months. Slopes and precipitation rates investigated are shown in Table 23.

TABLE 23. FEEDLOT SLOPE AND PRECIPITATION RATES STUDIED IN THE TILTING TABLE EXPERIMENT

Surface Slope (Percent)	Precipitation Rate (Inches Per Hour)
1	1
1	2
1	3
3	1
3	2
3	3
6	1
6	2
6	3
9	1
9	2
9	3

Data obtained in these experiments indicated that the concentration of pollutants in feedlot runoff is highly independent of both feedlot slope and precipitation rate. The pattern of a high concentration of pollutants in the initial runoff followed by a leveling off of concentration after about 30 minutes was repeatedly observed in samples obtained from concrete feedlots during precipitation. However, it will be noted that concentrations of pollutants in the runoff from the tilting table were generally almost an order of magnitude less than the concentrations found in runoff from actual feedlots. The reason for this large discrepancy is not known, but it is believed to be largely influenced by the mixing action of cattle hooves as the cattle move about on the feedlot surface during rainfall. This same animal action also probably accounts for the much greater penetration of precipitation through the manure pack on an actual feedlot than was observed in this series of experiments.

Typical results obtained in these experiments are plotted in Figures 12 through 23.

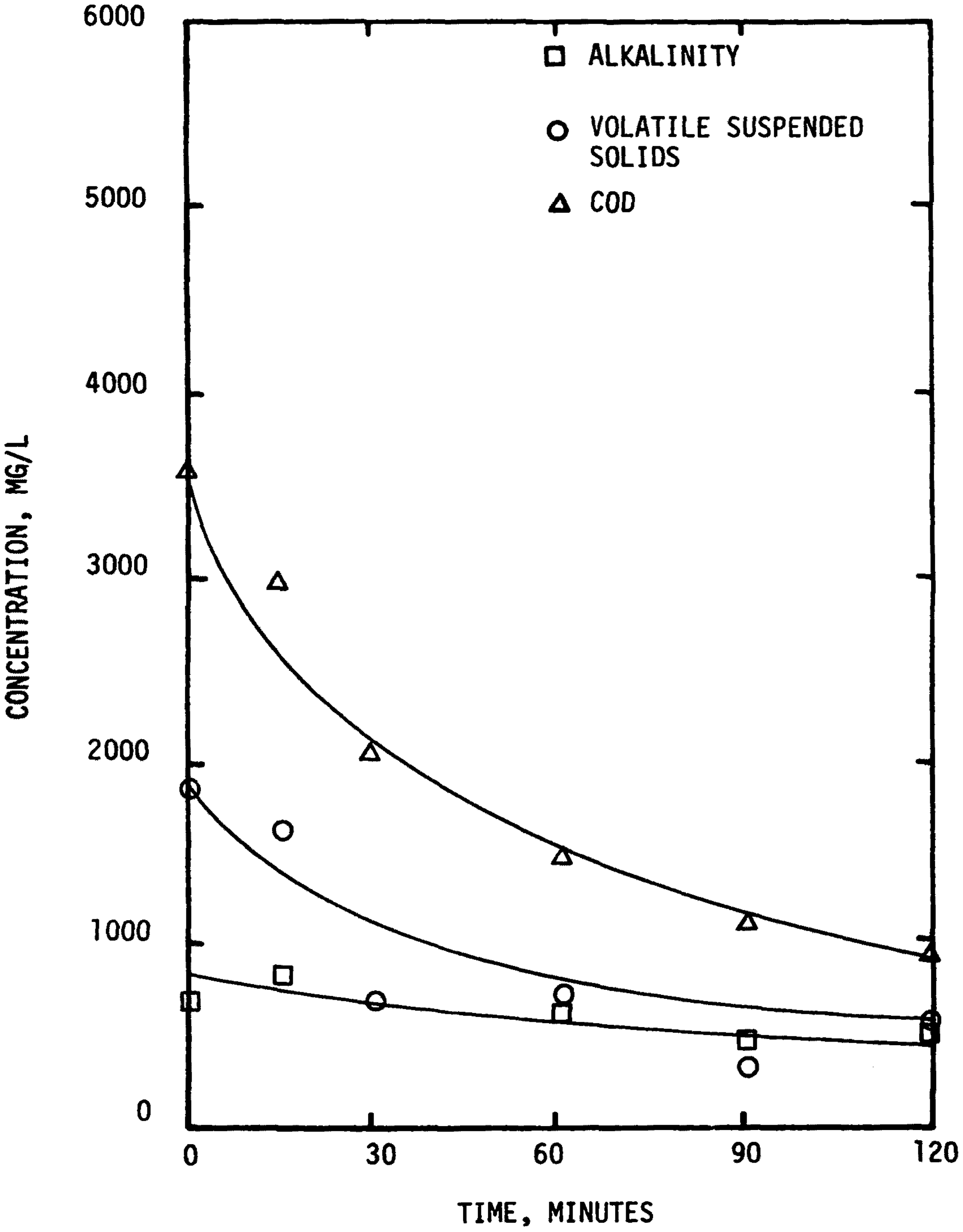

FIGURE 12. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF ONE PERCENT AND PRECIPITATION RATE OF ONE INCH PER HOUR.

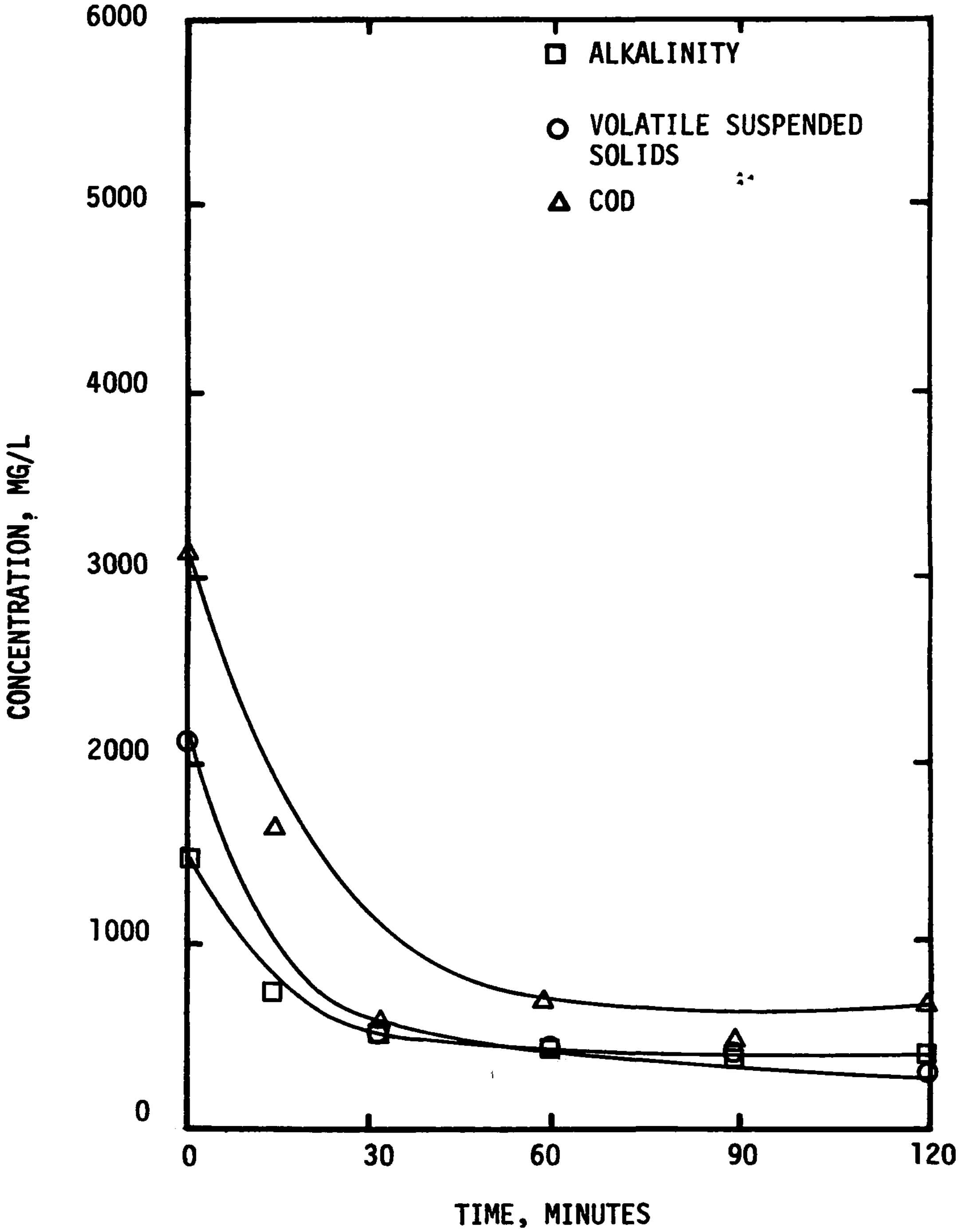

FIGURE 13. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF ONE PERCENT AND A PRECIPITATION RATE OF TWO INCHES PER HOUR.

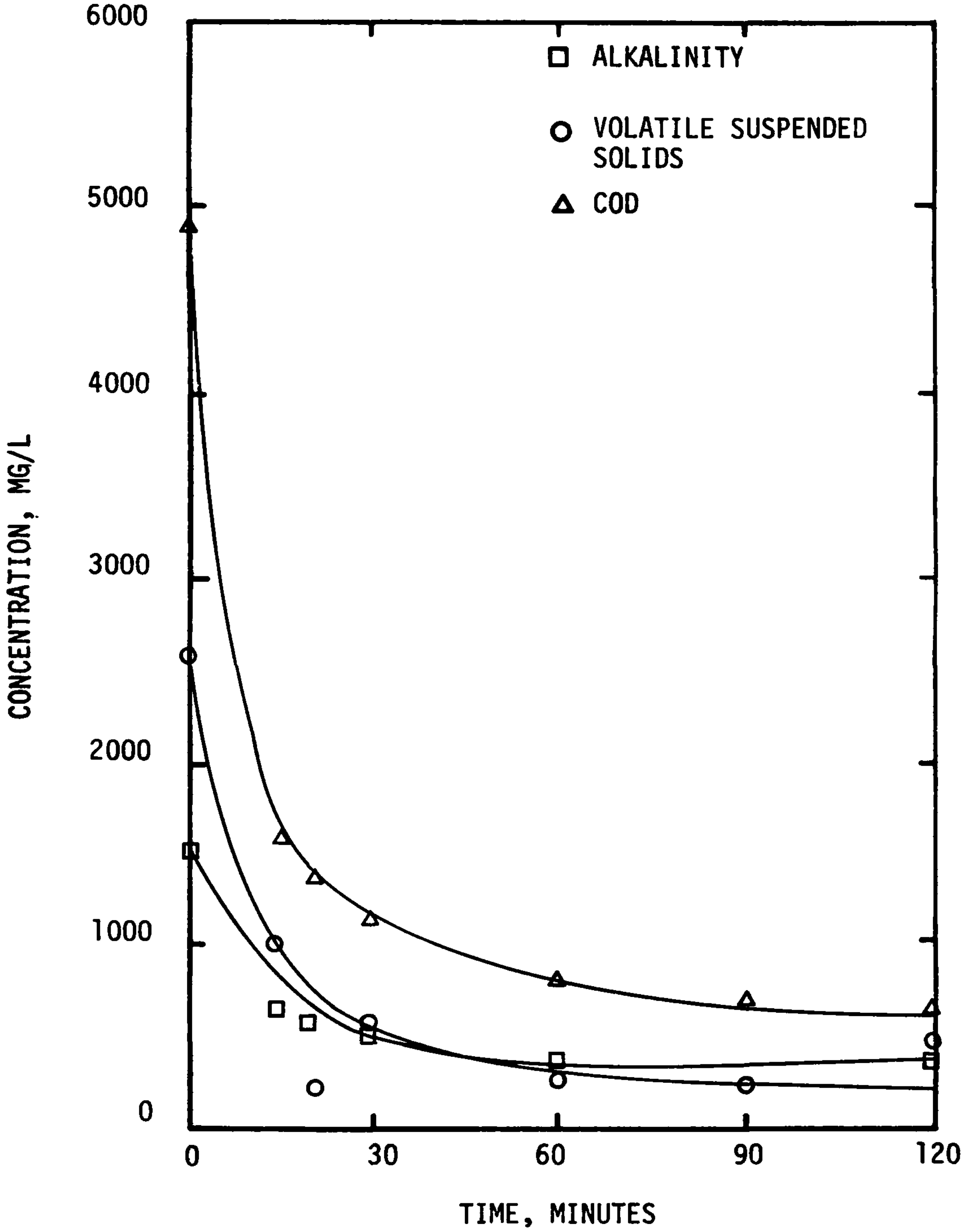

FIGURE 14. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF ONE PERCENT AND A PRECIPITATION RATE OF THREE INCHES PER HOUR.

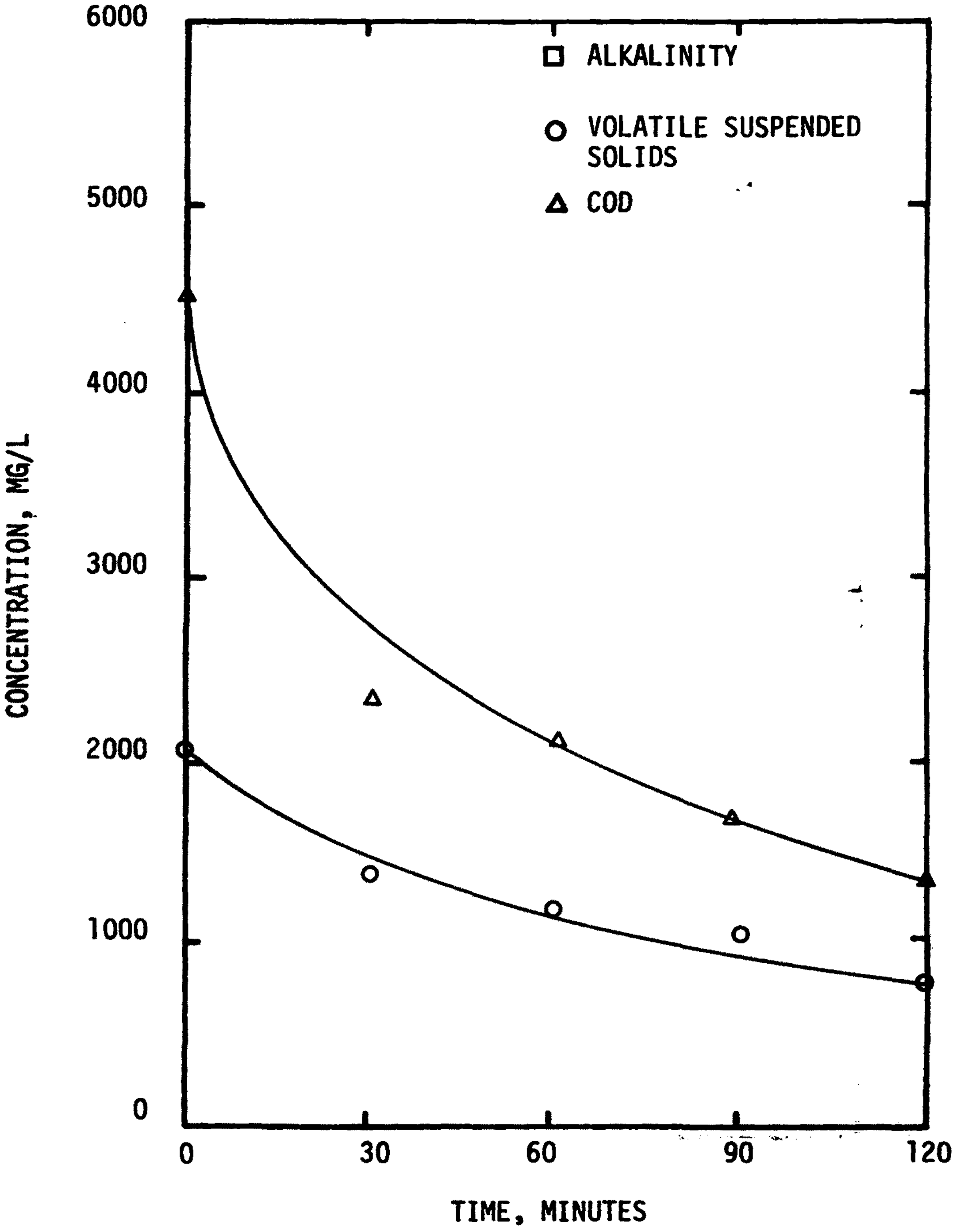

FIGURE 15. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF THREE PERCENT AND A PRECIPITATION RATE OF ONE INCH PER HOUR.

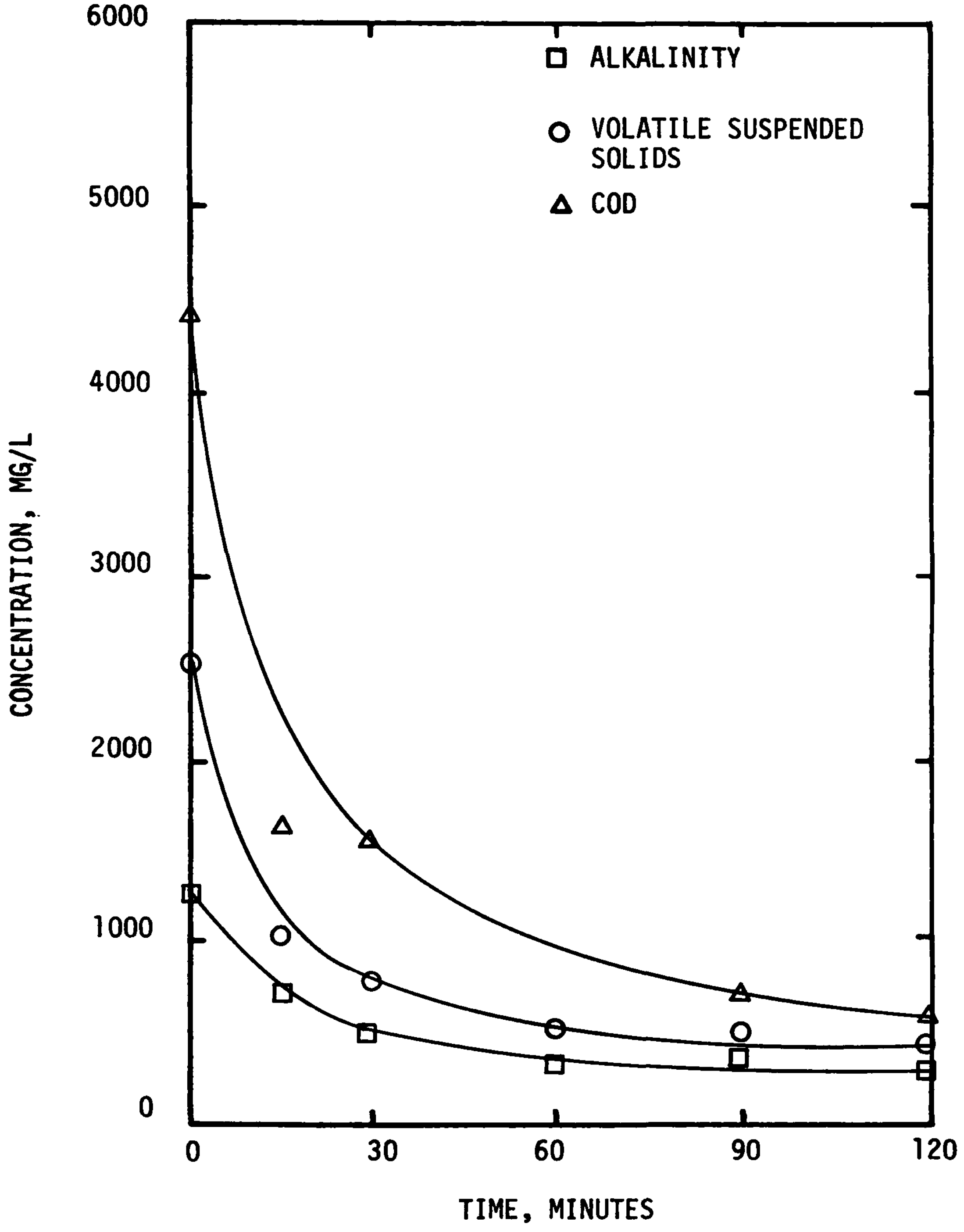

FIGURE 16. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF THREE PERCENT AND A PRECIPITATION RATE OF TWO INCHES PER HOUR.

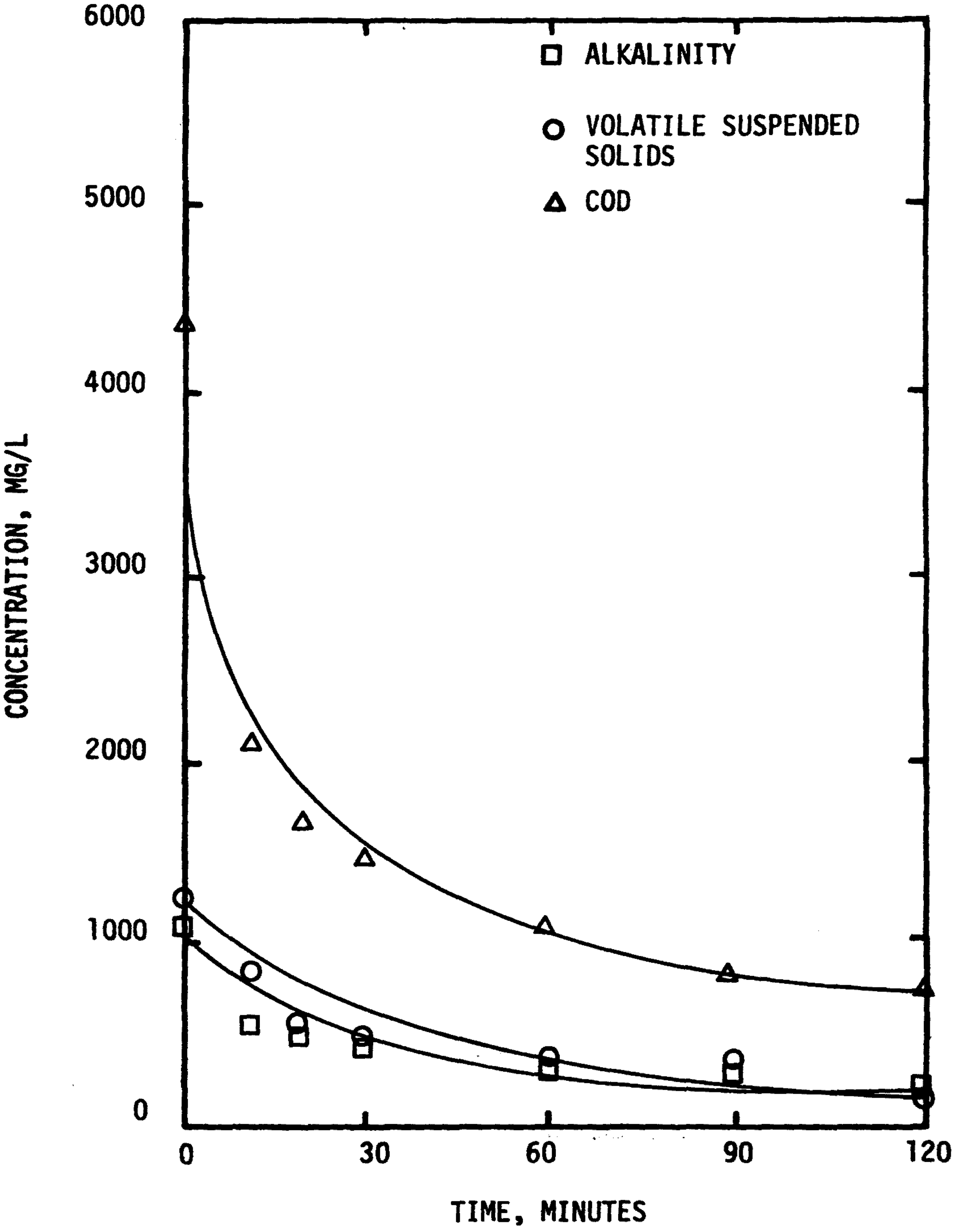

FIGURE 17. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF THREE PERCENT AND PRECIPITATION RATE OF THREE INCHES PER HOUR.

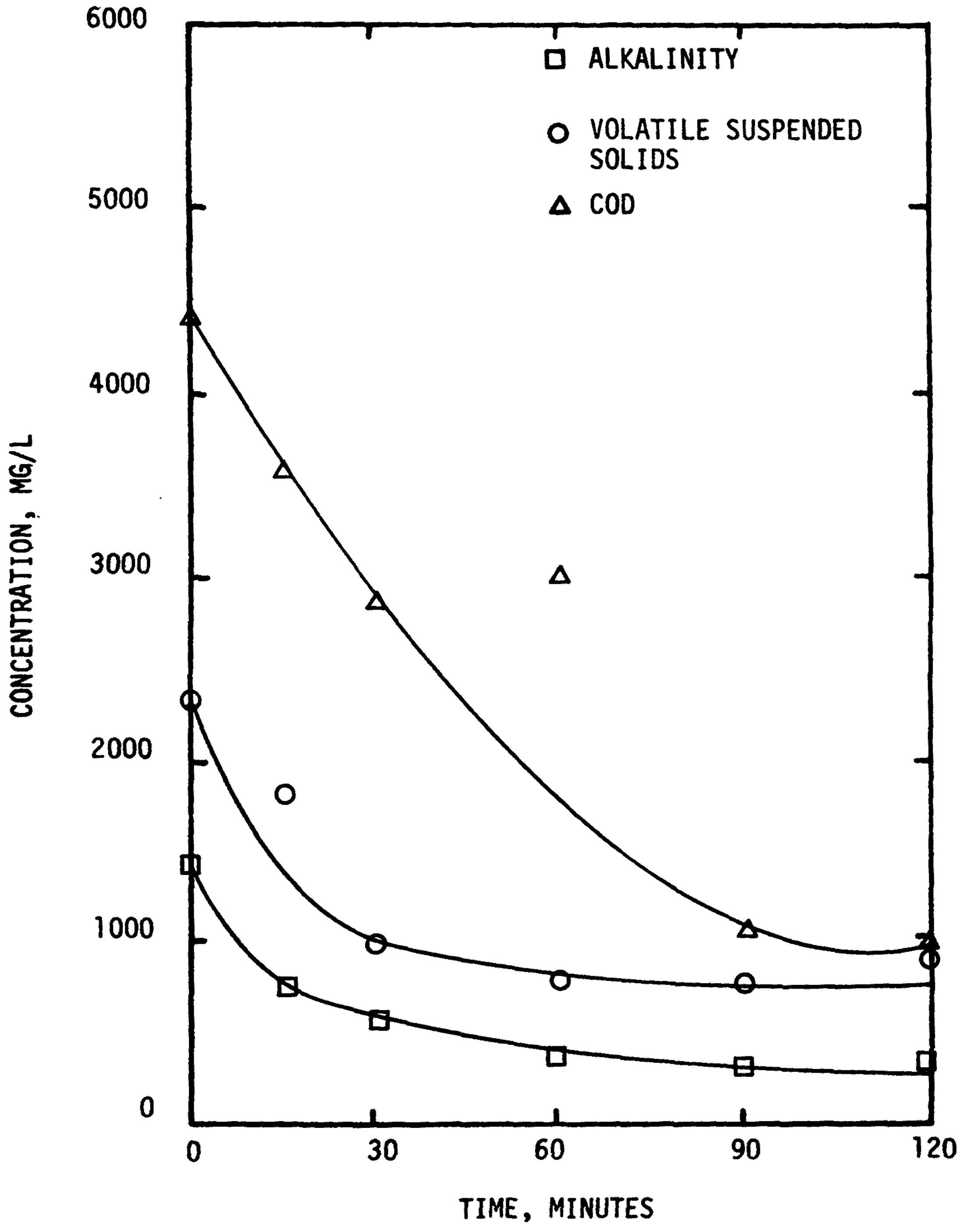

FIGURE 18. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF SIX PERCENT AND PRECIPITATION RATE OF ONE INCH PER HOUR.

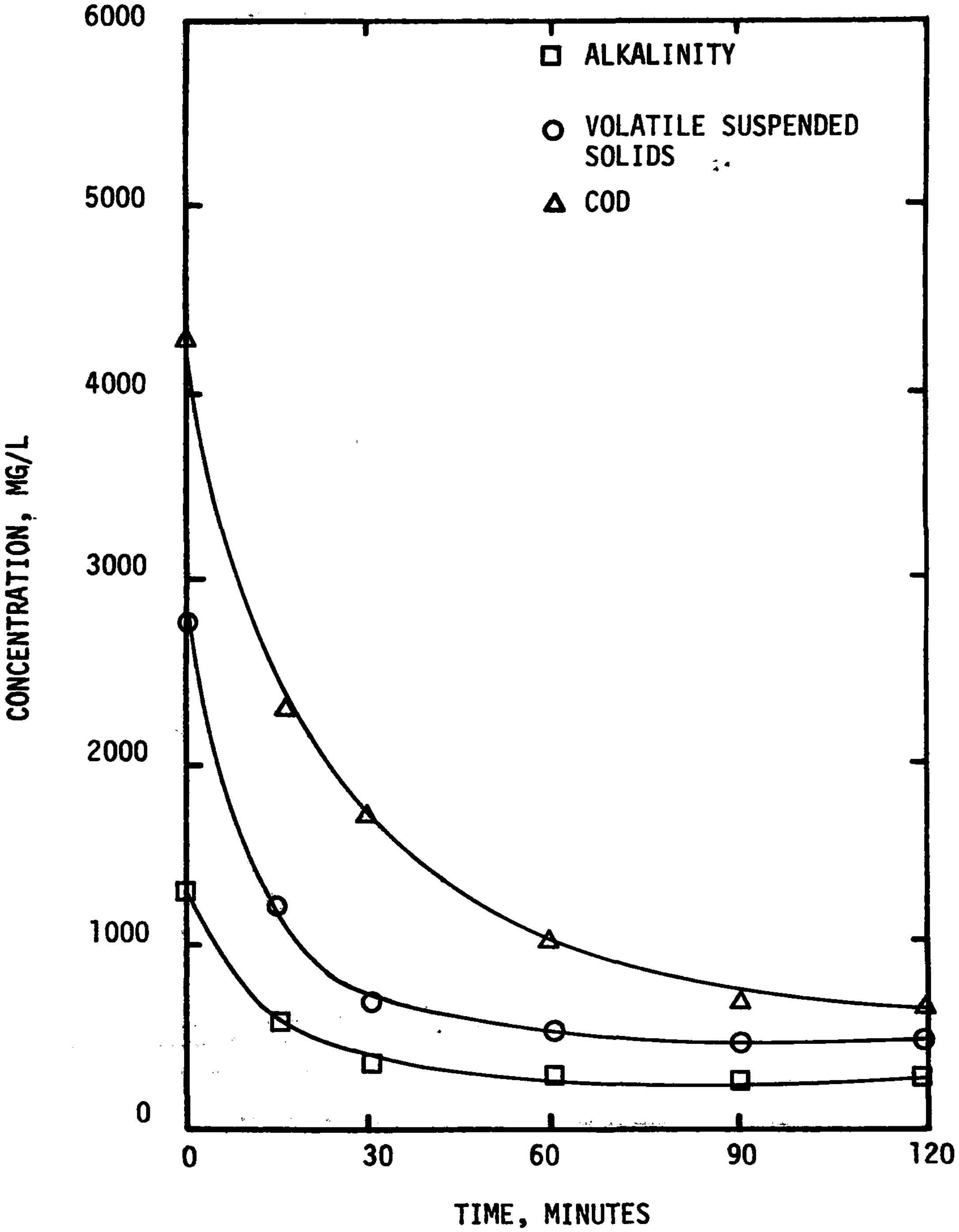

FIGURE 19. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF SIX PERCENT AND PRECIPITATION RATE OF TWO INCHES PER HOUR.

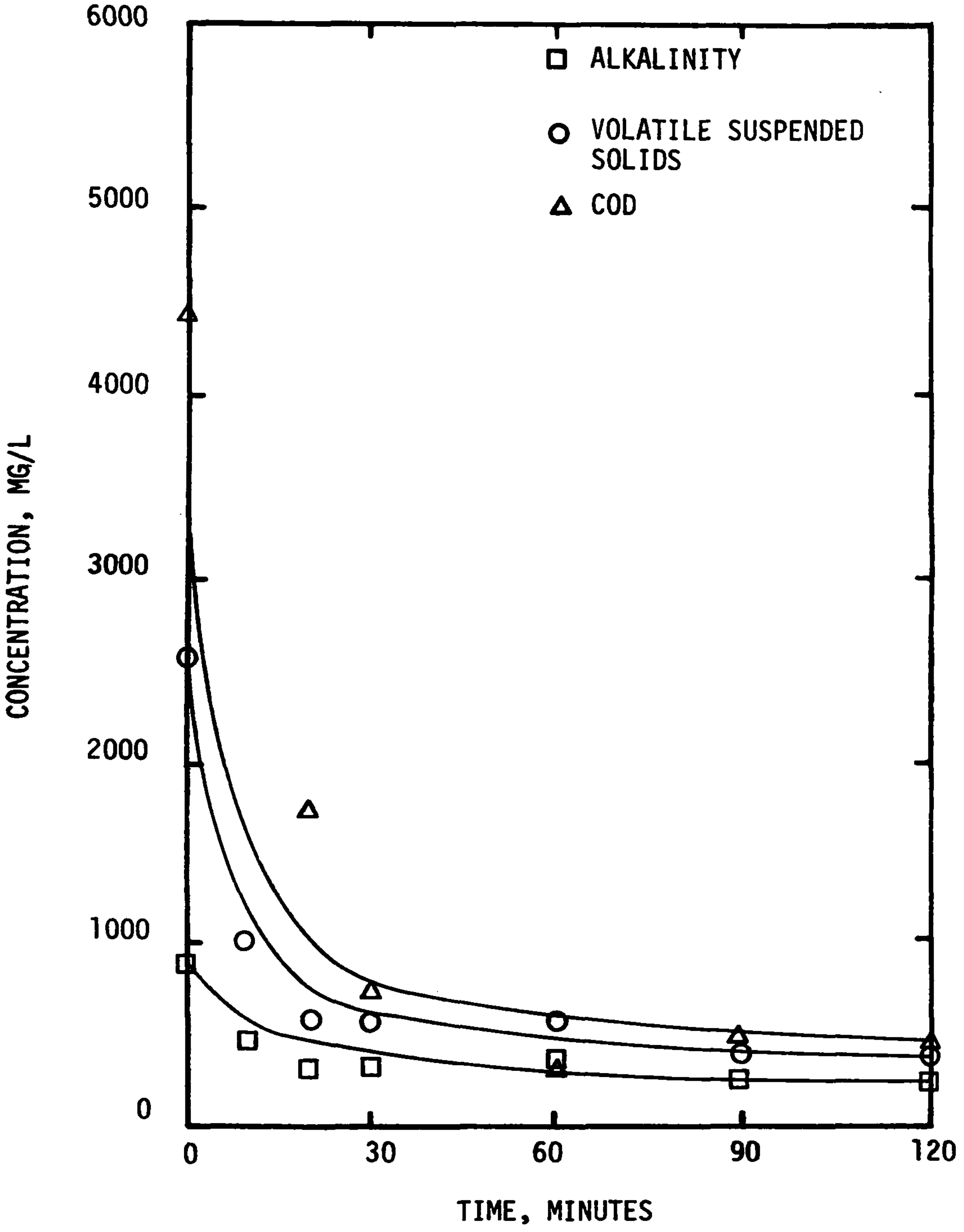

FIGURE 20. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF SIX PERCENT AND PRECIPITATION RATE OF THREE INCHES PER HOUR.

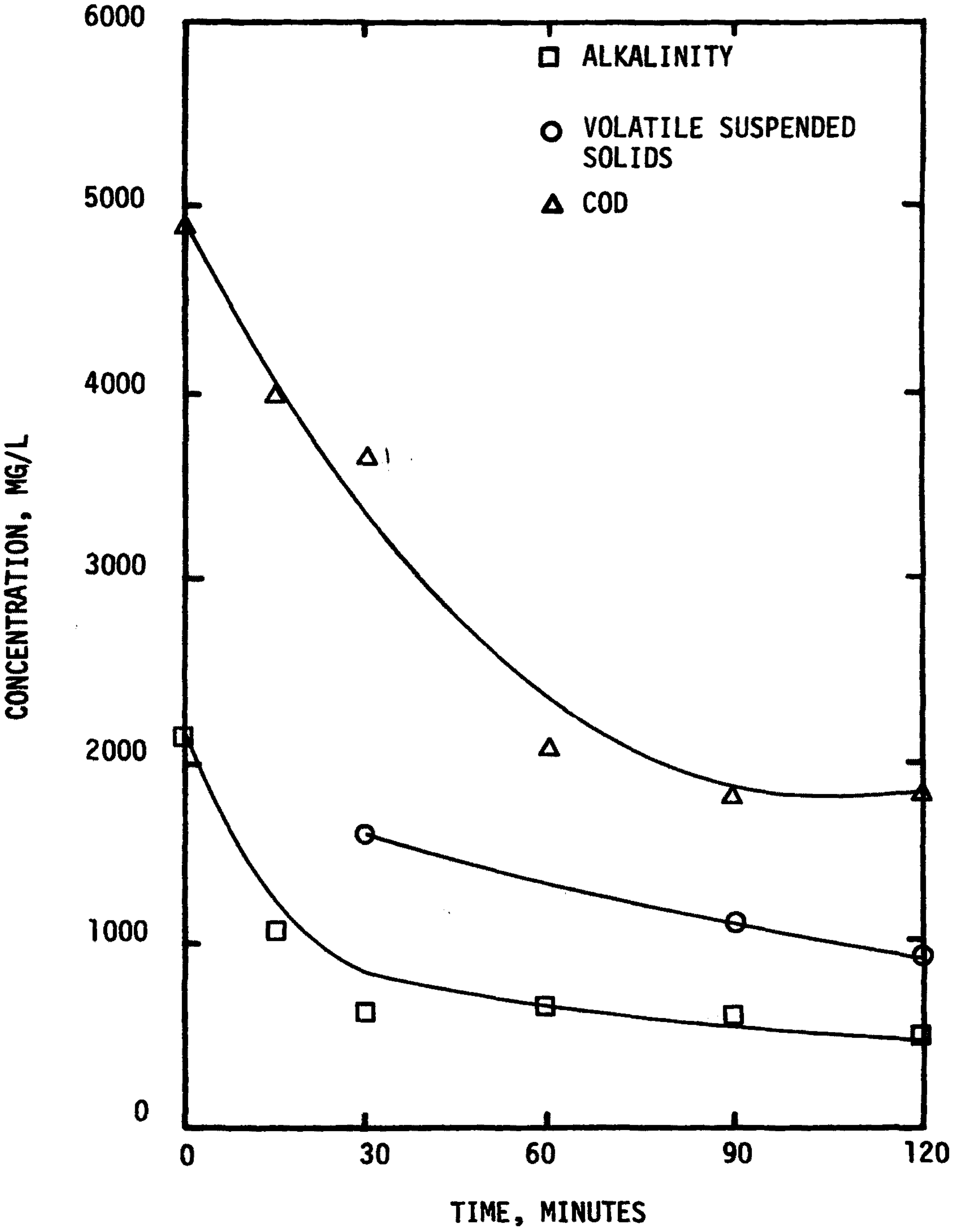

FIGURE 21. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF NINE PERCENT AND PRECIPITATION RATE OF ONE INCH PER HOUR.

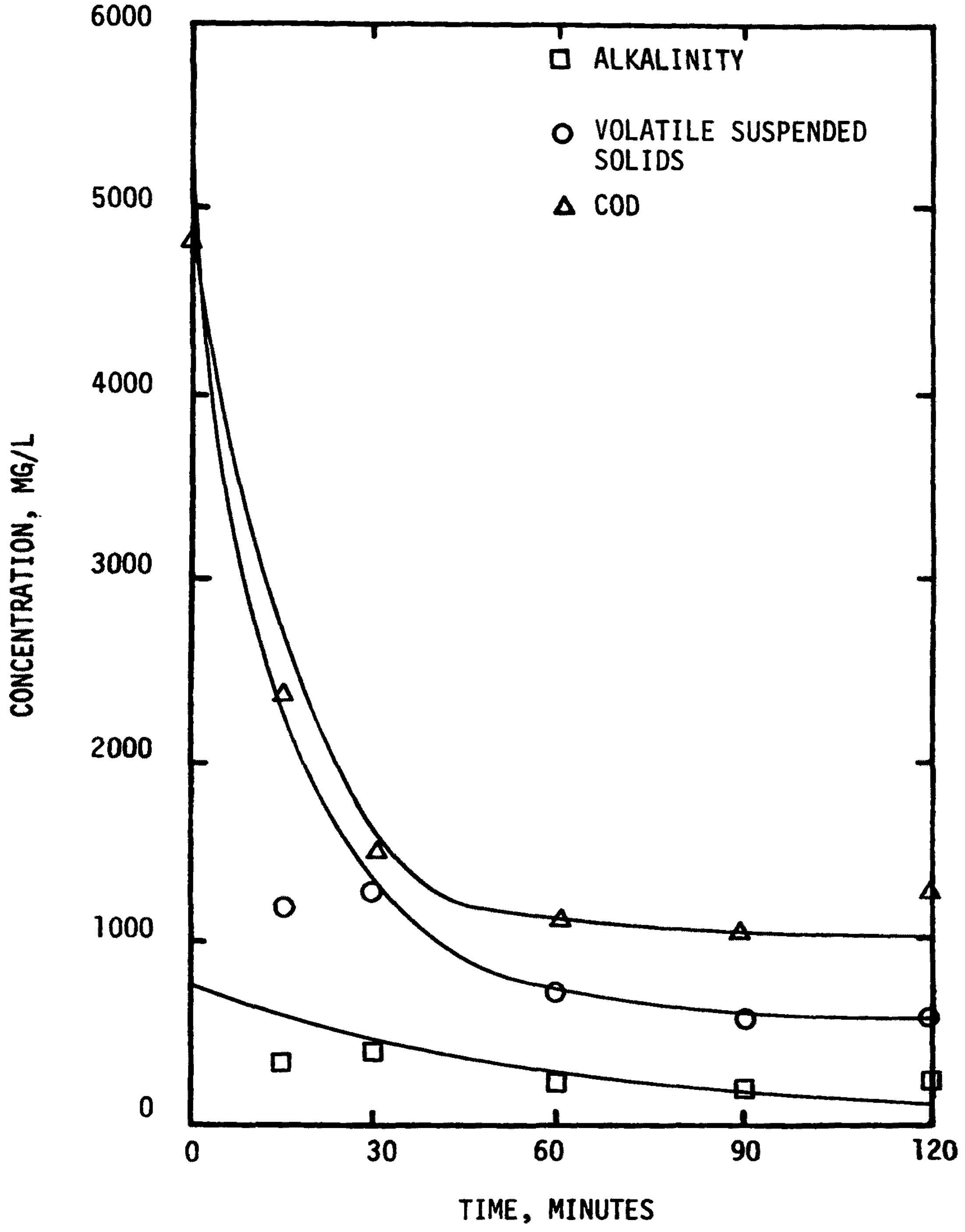

FIGURE 22. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF NINE PERCENT AND PRECIPITATION RATE OF TWO INCHES PER HOUR.

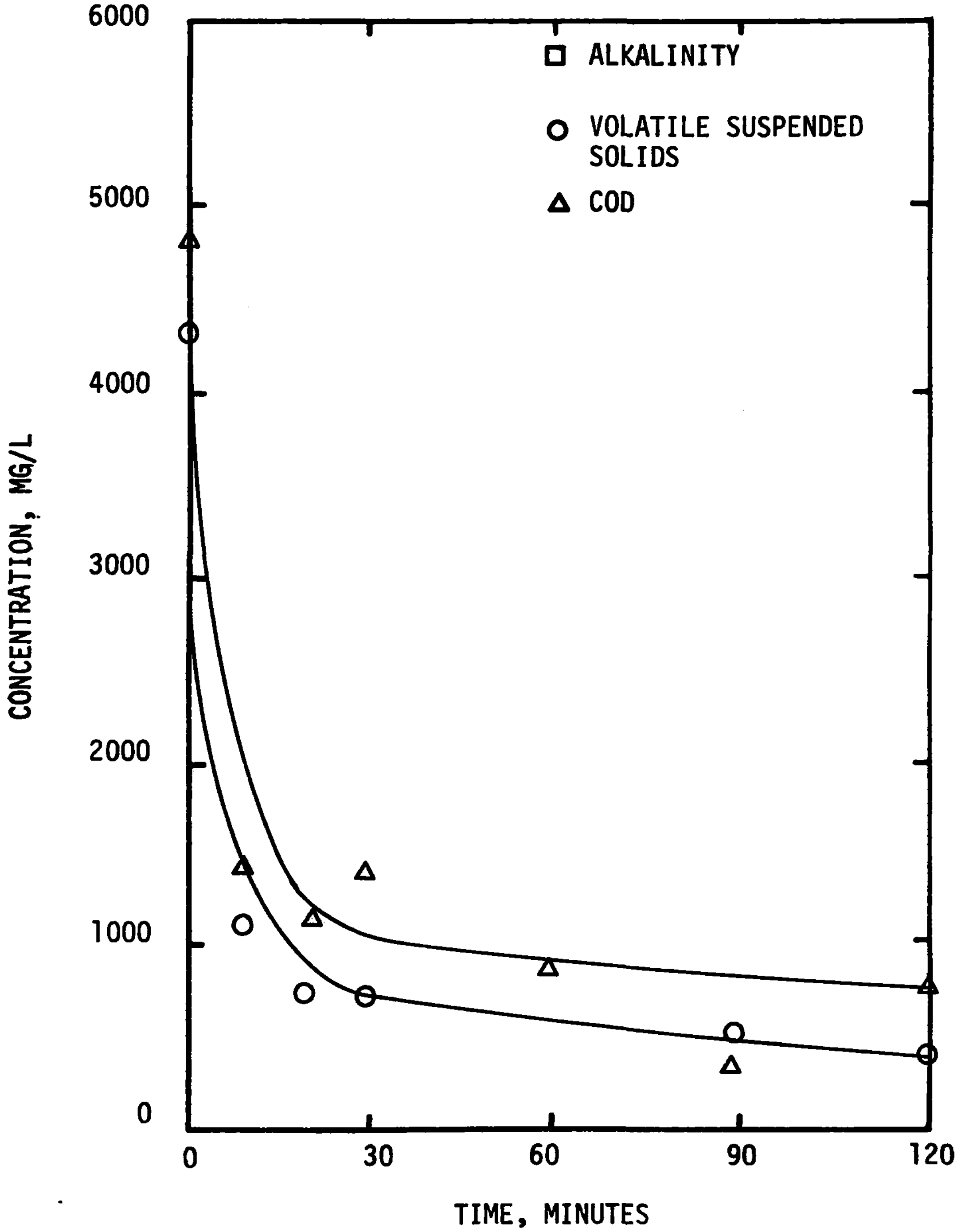

FIGURE 23. POLLUTANT CONCENTRATIONS IN SIMULATED FEEDLOT RUNOFF FOR A FEEDLOT SLOPE OF NINE PERCENT AND PRECIPITATION RATE OF THREE INCHES PER HOUR.

RELATED RESEARCH AT TEXAS TECH

Composting Studies

In an attempt to study possible means of stabilizing beef cattle feedlot solid waste, a three and a half year aerobic composting research project was initiated at Texas Tech University and funded by the Farmstead Engineering, Livestock Engineering and Farm Structures Research Branch, AERD, ARS, USDA.

The study is being conducted in the vicinity of Lubbock, Texas, using accumulated waste collected from commercial and research beef cattle feedlots during different times of the year to determine the effects of climate on the compostibility of the solid waste material. Waste has also been collected from cows fed various commercial rations and maintained on different management systems involving open and covered lots, paved and unpaved surfaces, and different population densities. Some of the collected waste was allowed to form a normal moisture balance with the atmosphere while other samples were taken from lots in which the accumulated feedlot waste was kept continuously moist.

Research involving the aerobic stabilization of solid material was conducted in specially designed drum digesters and in open air piles. In both cases, physical, chemical, and biological data were collected during the digestion periods. Each container was constructed from a fifty-five gallon drum mounted to allow rotation about the cylindrical axis. An air distribution system was installed to inject metered temperature- and humidity-controlled air into the test sample. Heat transfer from the drum was limited by a blanket insulation about the drum surface. The drums were located in a controlled environment room. Temperature within the mass was continuously recorded and exhaust gas samples were periodically taken from each digester.

Composting in piles was conducted in the open. The piles were varied in size and shape to establish the effects of the physical dimensions on the composting process.

Research Findings

All beef cattle feedlot waste materials from all lot surfaces, feeds, and management systems were found to be compostible to a final uniform state, although the rate of composting and the condition of the material during the composting process varied greatly. Considerable variation existed in initial physical, chemical, and biological characteristics of the waste as collected from the feedlot surface. This variation was the result of the differences in feed, population densities, climatic conditions, and waste management during the period of accumulation.

Feed types studied ranged from all-concentrate to high roughage content feeds. All types stabilized readily, although the rate of stabilization was greater with high roughage content than with all-concentrate feeds. Two factors seem to be involved: the particle size and the C/N ratio. The uniformly small-sized particles of all-concentrate feeds possessed a higher degree of compaction and a smaller void ratio. In addition, the material readily caked to form lumps which restricted the flow of air through the mass. As a result of the limited oxygen supply, areas within the all-concentrate waste became anaerobic. Waste materials containing larger organic particles were less compact and optimum air movement was obtained more easily. As a result, the entire mass remained aerobic and biological activity continued at a higher level.

Carbon-Nitrogen Ratio

The C/N ratio of the accumulated waste varied from 35 to 9 according to feed type, degree of stabilization, and climatic conditions during accumulation. These factors were interrelated and specific effects of each have not been determined. In all cases tested, waste material with both high and low C/N ratios were successfully stabilized, although the rate of composting and the temperature of the mass varied considerably. Little difference in composting rate was noted when the C/N ratio was above 30. When the C/N ratio ranged below 25, the rate of stabilization was considerably slower. In some cases, up to two months were required for the internal temperature of the composting mass to drop to within 5° C of the ambient temperature. This compared with a composting time of two to four weeks for waste with more nearly optimum C/N ranges.

The rate of loss of carbon and of nitrogen varied during composting. Carbon loss appeared to take place during the entire process while nitrogen loss as ammonia gas occurred mostly during the early stages of stabilization when the temperature of the mass was at its peak. Since these rates varied, the C/N ratio first increased during the early stages of composting then later decreased as the release rate of ammonia diminished.

Partial stabilization of moist accumulated waste on the feedlot surface was evident during warm weather periods. This biological decomposition of waste during the accumulation period resulted in a reduction of composting time and composting temperatures. When waste accumulated in a dry state during cold or hot weather, little stabilization was evident and the full composting cycle was required. Waste accumulated during cold weather retained the biological vigor of fresh manure even when it remained moist on the feedlot floor.

The means by which the waste was kept moist on the lot did not materially affect the stabilization during the accumulation period. High moisture content waste was obtained by natural rainfall, by artificial sprinkling, or by maintaining a high animal population density on the lot. In either case the degree of stabilization was the same provided the depth of accumulated waste was equal. During wet weather the waste remained drier on the roofed lots than on uncovered lots, but at high animal population densities little difference was noted in the composting time.

Moisture Content

On a wet weight basis a moisture content of at least 30% was required for aerobic composting. Limited composting was evident at lower moisture levels, but at a greatly reduced biological activity rate and at lower temperatures. At moisture levels in excess of 50% in high concentrate feeds and in excess of 60% in high roughage feeds, a reduction of the rate of stabilization was noted. This probably was the result of the reduction of void spaces within the mass and the partial oxygen starvation of the aerobic organisms.

Insect Infestation

The moist waste as collected from beef feedlots was an extremely attractive material for flies. The attraction seemed to increase during the very early stages of composting until the temperature of the mass exceeded 50° C for over 24 hours. During the later stages of composting no fly attraction or activity was noted. The high temperatures of aerobic stabilization killed the larvae and eggs in the mass and no live larvae were found after composting.

Oxygen Requirements

The oxygen requirements necessary for aerobic stabilization varied with the rate of biological activity, being greatest during the early stages of composting when the temperature of the mass was highest. Oxygen requirements dropped sharply later in the composting process.

When the air supply rate per 100 pounds of manure exceeded three liters per minute, the temperature of the mass dropped and the rate of composting decreased. This seemingly was the result of excessive cooling by the supply air. At air supply rates below 1.5 liters per minute, the rate of composting decreased due to oxygen starvation. The optimum supply rate for the peak composting period ranged between 1.5 and 3 liters per minute per 100 pounds of organic material. During the later stages of composting, the oxygen requirements decreased with the biological activity level. Maximum biological activity was also noted when the oxygen level in the exhaust gases ranged from 10 to 12%. Below 5% oxygen a sharp reduction in heat production was noted and the time for stabilization was considerably lengthened. Above 12% oxygen excessive cooling and dehydration occurred. Particle size also affected the rate and degree of stabilization. When dense lumps of waste exceeded 1 inch in diameter, aerobic stabilization occurred around the surface while the center of the lump remained anaerobic.

Drum Stabilization

Several problems were encountered during preliminary aerobic digestion trails. The first involved the system used to supply oxygen to the aerobic digestion process. This air, supplied by a compressor, had a low moisture content and caused considerable evaporative cooling to take place within the mass. With this excessive cooling, thermophylic digestion was not established. A modification in the supply system to saturate and heat the injected air resulted in a rapid biological start in the composting process reaching full thermophylic activity within 24 hours.

Air was injected into the organic mass through a perforated pipe located on the bottom of the drum extending along a line parallel to the cylindrical axis. The air tended to channel upward through the waste, to supply air unevenly, and to create areas of varying bacterial activity. The drums were rotated to provide uniform air distribution and to blend the areas of uneven temperatures. Continuous mixing caused the organic particles to adhere and form large balls and rolls of slightly compacted waste. Balling occurred at moisture levels above 50% on most waste materials tested. When mixing was limited to five revolutions twice daily, no balling occurred and no reduction of activity was noted. Waste from high-roughage feeds had less tendency to ball than that from low-roughage high-concentrate feeds.

In the low-roughage waste, air readily channeled at moisture levels in excess of 45%. This channeling was found to develop within an hour of mixing and resulted in an uneven distribution of air through the mass.

Time for Stabilization

The organic waste expended its ability to maintain high temperature digestion in about ten days under the most nearly ideal conditions. The heat produced by bacterial action during this time period caused the temperature to rise to an early peak and then to decrease gradually to within 5° C of the ambient air, forming a classical composting curve. During the composting cycle the average decreases in volume and weight of dry matter were 24% and 32%, respectively. The total weight of potassium and potash remained constant, but increased per unit dry matter. Nitrogen was lost as ammonia gas early in the digestion process, but on a unit dry matter basis its concentration increased slightly during the composting period.

Open Air Piles

Waste was composted in open air piles throughout the year. Management was critical during dry weather since the outer layer of the pile dehydrated rapidly. The addition of water was required at mixing to maintain a moisture level of over 40 percent.

Mixing of the piled organic mass served to control the infestation of the fly larvae at the surface during the early stages of composting by killing the fly larvae and eggs in the high temperatures of the pile interior.

Mixing of the piles also introduced oxygen to the interior of the pile and mixed the areas of varying biological activities. Composting required considerably more time in open air piles than in controlled digesters since the stabilization process did not progress uniformly. In both digester and open air piles, the final product of biological digestion by composting was similar.

Summary

The organic stabilization of beef feedlot waste by composting is a feasible process. Organic beef feedlot waste is compostible in either specially designed digesters or in exposed open air piles, to a biologically stable organic product, free from noxious odors and insect infestation. Stabilized waste can be stored in a wet or dry state without danger of heating, attracting insects, or causing noxious odors. The time of stabilization depends on the type of original feed material, the condition of the waste at the start of the composting period, and the management of the composting process. Composting requires skilled management to obtain satisfactory results.

Agronomic Studies

The primary objective of the agronomic research was to determine the usefulness of cattle feedlot runoff for crop production.

The runoff materials used in these studies came from both dirt and concrete-surfaced feedlots.

Runoff was also obtained from differing slopes of dirt-surfaced lots. Runoff used resulted from both natural rainfall and artificial flushing or washing. These runoff materials were used in studies in growth rooms either directly as they came from the catch pits or diluted with water, on cotton, grain sorghum, wheat, barley, rye, soybeans, and bermuda grass, all commonly grown crops in the irrigated area of West Texas. Original treatments ranged from two to eight surface inches, either biweekly or weekly, in an attempt to determine the upper limit of feedlot runoff that could be used in crop production. Results of these studies indicated that plant species vary greatly in the amount of feedlot runoff they can tolerate. Bermuda grass was the most tolerant, grain sorghum the next most tolerant, small seeded winter annuals relatively intolerant, cotton intolerant, and soybeans very intolerant. The germinating and tender seedling stages of field crops were shown to be most susceptible to damage.

Runoff from concrete lots appeared to be about twice as damaging as runoff from dirt lots. Crop damage was positively correlated with type of ration on dirt-surfaced lots. Seven weekly applications of two surface inches of runoff from a dirt surface feedlot applied weekly increased bermuda grass growth by 17 percent, decreased grain sorghum growth by 60 percent and decreased wheat growth by 72 percent. A similar treatment with concrete-surfaced feedlot runoff decreased bermuda grass growth by 70 percent, decreased grain sorghum growth by 88 percent, and decreased wheat growth by 99 percent plus.

In germination tests six surface inches of dirt feedlot runoff applied over a three week period reduced grain sorghum germination by 25 percent, reduced cotton germination by 33 percent, and reduced wheat germination by 30 percent, whereas six surface inches of concrete feedlot runoff applied over the same period of time reduced grain sorghum germination by 75 percent. Studies under field conditions and undisturbed soil tended to confirm the basic finding noted in small plots and in growth rooms.

Biweekly application of two surface inches of feedlot runoff applied to well established cotton and grain sorghum that are five to six weeks old does not appear to be so damaging. In some instances, it can be beneficial in crop growth, and single applications of up to four surface inches of feedlot runoff can be beneficial to crop growth if applied to well established crops. Soil analyses for soluble salt, sodium, and chloride, indicate that these minerals are accumulating in the top 24 inches of soil profile.

On soils receiving seven biweekly applications of two surface inches of runoff from concrete feedlots, soluble salts in the top 30 inches increased 3,321 pounds per acre, from 7,989 pounds to 11,310 pounds. Sodium increased 805 pounds per acre. Nitrate nitrogen increased somewhat but was highly variable depending upon crop growth and time of sampling.

In summary, livestock feedlot runoff offers potential as a resource to be used for crop production. It should not be applied in large quantities to soil immediately before planting nor to tender seedlings. It can be applied to established crops if care is taken as to amounts, source, and crop species.

ACKNOWLEDGMENTS

The support by the Environmental Protection Agency of the research on which this report is based is hereby gratefully acknowledged. The Animal Science Department of Texas Tech University also contributed substantially to the project and this contribution is most sincerely appreciated.

Some of the data presented in the report were obtained from a parallel study funded by the Farmstead Engineering, Livestock Engineering and Farm Structures Research Branch, ERD, ARS, USDA. This support is also sincerely appreciated and is hereby gratefully acknowledged.

The Texas Water Quality Board has provided continuing support for the agronomic studies which are summarized in the report, and its support is most sincerely appreciated.

The support of all three agencies, which made possible better coordinated total effort than would otherwise have been possible, has improved the effectiveness of the entire research program, and the willingness of all three agencies to become involved in such a cooperative program is most commendable.

The assistance of Mr. Marion R. Scalf, Project Officer for EPA, in expediting the work and in reviewing the manuscript promptly is sincerely appreciated.

The research performed by Donald L. Spraggins, John Malouf, Dong Soo Whang, Leonard Keeton, D. W. Keeling, and J. L. Winstead, all graduate students at Texas Tech University, was of material benefit to the completion of the project, as was the very capable and willing assistance of Mr. Carl Carter, Technician in the Department of Agricultural Engineering.

Finally, the patience and skill of Mrs. Raynell Keller in typing and assembling the final manuscript are most sincerely appreciated.

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APPENDIX A

Analytical Procedures

Procedures detailed in Standard Methods for the Examination of Water and Wastewater, USPHA, AWWA, WPCF, 12th Edition, were used for the routine analysis of runoff samples. However, in order to improve accuracy and repeatability of results, one modification was adopted. This modification consisted of breaking off approximately two millimeters of the end of volumetric pipettes used in measuring samples. This procedure increased the bore of the pipette substantially and permitted passage of the larger particles that were commonly found in runoff without substantially changing the volume of liquid contained in the pipette. This procedure was particularly important in obtaining repeatable results with BOD and COD tests, and was of less importance in obtaining repeatability of other tests.

Procedures recommended by the manufacturer were followed carefully in analyzing samples on the Hewlett-Packard CHN Analyzer.

1 *Accession Number*

W

2 *Subject Field & Group*

05 B

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 *Organization*

Texas Tech University Water Resources Center
Lubbock, Texas

6 *Title*

Characteristics of Wastes from Southwestern Cattle Feedlots

10 *Author(s)*

Wells, Dan M.
Albin, R. C.
Grub, Walter
Coleman, Eugene A.
Meenaghan, G. F.

16 *Project Designation*

EPA, WQO Grant No. 13040 DEM 01/71

21 *Note*

22 *Citation*

23 *Descriptors (Starred First)*

*Runoff, *Livestock, *Characteristics, *Cattle Feedlots

25 *Identifiers (Starred First)*

*Southwestern Cattle Feedlots, *Quality of Runoff

27 *Abstract*

Research was conducted on the experimental feedlots in Lubbock, Texas, to determine the characteristics of wastes from Southwestern cattle feedlots. The feedlots were generally operated in a manner conforming to normal commercial feeding operations in the area. They were provided with collection pits and allowed the quantity of runoff to be measured accurately, and samples of runoff were collected routinely both during rainstorms and from the collection pits. Manure samples were also collected routinely for analysis.

Results of the research show that the quantity of runoff per unit area of concrete-surfaced lots is substantially greater than the quantity per unit area of dirt-surfaced lots, and that the concentrations of pollutants in concrete-lot runoff are substantially higher than corresponding concentrations in runoff from dirt-surfaced lots.

The quantity of solid waste derived from cattle being fed an all-concentrate ration is less than half as great as the quantity derived from cattle being fed a 12 percent roughage ration. Additional studies showed that all solid waste derived from cattle feeding operations are readily compostible, although the rate of composting is influenced to some extent by the type of ration, moisture content of the waste on the feedlot floor, and other factors. Agronomic studies indicate that runoff can be used for irrigation of crops, but extreme caution is required in the application of runoff to crops to prevent damage to them.

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WR:102 (REV. JULY 1969)
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