AN ABSTRACT OF THE THESIS OF

GARY BERT TUCKER for the MASTER OF SCIENCE
(Name of Student) (Degree)

in Soil Science presented on March 27, 1974
(Major) (Date)

Title: DISPOSAL OF DAIRY COW WASTE SLURRIES ON AMITY SILTY CLAY LOAM SOIL

Abstract approved: Redacted for privacy
V. V. Volk

Intensification of livestock operations has enhanced the problem of animal waste disposal. Since high application rates of the waste to soils would help elevate the problem, a study was established to determine water quality as affected by applications of dairy waste slurries to tiled and untiled soils.

Dairy cow waste slurries were applied to tiled and untiled Amity sicl soil at rates of 0, 400 and 1000 gallons per plot or 0, 3.0 and 8.0 acre-inches per acre. The waste was applied during the winter, summer and fall of 1971. In a subsidiary study several acre inches of dairy waste slurry were applied to an agricultural tiled field of Amity silty clay loam (sicl) soil during the winter of 1972.

Dairy cow waste slurries, tile drain effluents and groundwater were assayed for total solids, total-N, total P, NH_4-N and NO_3-N content. Water samples were collected prior and subsequent to waste application.

During the winter application period the NH_4-N concentration in both groundwater and tile effluent was < 50 ppm and with time decreased to < 10 ppm. The NH_4-N concentration in the applied waste slurry averaged 100 ppm. The NH_4-N concentration in tile effluent and groundwater from control plots was < 1 ppm. The total -N concentration in the tile effluent and groundwater were approximately twice the assayed NH_4-N concentration.

During the summer application period, the NH_4-N concentration in tile effluent and groundwater was higher than in the winter months after the waste slurry application. The Amity sicl soil cracked severely during the summer months and allowed some preferential flow of the waste directly to the tile drains or groundwater sample tubes.

The NO_3-N concentration in the effluent and groundwater increased from < 1 ppm in the winter to 9 ppm in the summer due to the increased microbiological activity.

The total P fixed by the undrained Amity soil decreased from 90% during the January application to 40% during the May 1971 application. The total P fixation by the undrained Amity sicl soil was 50 to 90% for both the sodded and desodded plots during the summer application period. The total P fixed by the tile drained Amity sicl decreased from 80% in January to 40% in February and remained constant for the duration of the winter application period. The percent total P fixation for both the medium and high application rates was similar. The total P fixed by tile drained Amity sicl soil during the summer waste applications was similar to the low percent total P fixation of the winter application period. The low percent total P fixation resulted largely from minimal soil-waste contact time due to cracks in the undisturbed soil, channel formation in the tile trench backfill and the high hydraulic conductivity of the Amity sicl soil.

The fall, 1971 waste applications included soil moisture criteria to determine waste application frequency. The use of soil moisture criteria for waste applications did not improve water quality; but, water quality was improved when the surface soil became sealed to thus reduce the water percolation rate and extend the soil-waste contact time.

Nitrogen and P accumulated in the surface 12 inches of the Amity soil; however, the accumulations were lower than would be expected from the large elemental applications. Only 260 pounds of total-N per acre accumulated in the surface 12 inches of the Amity soil after receiving over 4400 pounds of total-N. Considerable NH_3 was probably lost at the time the waste slurries were applied. Besides NH_3 volatization, NO_3-N leaching, gaseous losses of N_2 or nitrogen oxides and the waste slurries rapid percolation through the soil contributed to the low total-N accumulation. The total-N, total P and NH_4-N level in the subsoil, 22 to 28 inch depth, remained relatively constant.

The NO_3-N concentration in the 0 to 12 inch layer of tile drained Amity soil increased from < 1 ppm during the winter to 35 ppm in the summer and then decreased to < 10 ppm in the fall. The NO_3-N concentration in the undrained Amity soil was 5 to 10 ppm greater than in the tile drained plots.

Approximately 80% of the applied total-P was fixed in the 0 to 12 inch layer of the Amity sicl soil. The percent total-P fixed by the soil very likely would be higher if P accumulations in the entire soil profile had been considered.

When the waste slurries were applied to the agricultural tiled soil, the soil removed 95 to 99% of the N and P. The total-N concentration in the ground water was < 10 ppm. The NH_4-N, NO_3-N and total P concentrations in the groundwater were generally < 2 ppm.

Although very little difference in water quality occurred between sodded and desodded plots in this research project, sodded application areas would increase retention and infiltration of waste slurries on steep slopes.

A recommended application rate to agricultural tiled soils would be one to two acre-inches of < 2% total solids waste slurry applied every three to four weeks. This application rate would prevent formation of a manure thatch and would reduce surface run-off problems.

A possible crop rotation program of corn, barley and pasture could be used. Corn and grasses are high utilizers of N. Corn utilizes approximately 400 pounds of N per acre. The net accumulation of total-N, before the crop is planted, ideally should not exceed 400 pounds of N per acre.

The application of waste slurries during the summer to soils that have a moderate to high content of shrink-swell clays is not suggested because of rapid waste percolation through the soil cracks into groundwater with minimal soil-waste contact.

Disposal of Dairy Cow Waste Slurries on Amity Silty Clay Loam Soil

by

Gary Bert Tucker

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1974

APPROVED:

Redacted for privacy

Associate Professor of Soil Science
in charge of major

Redacted for privacy

Head of Department of Soil Science

Redacted for privacy

Dean of Graduate School

Date thesis is presented March 27, 1974

Typed by Ilene Anderton for Gary Bert Tucker

ACKNOWLEDGEMENTS

I wish to thank my wife, Nancy, for her patience and tolerance while completing my requirements. I also wish to thank Dr. V. V. Volk for his guidance and suggestions during the preparation of the thesis.

Gratitude is also extended to Dr. Myron Cropsey, the co-project leader, for his assistance and supervision during the progress of this study.

Acknowledgement is also extended to the Department of Animal Science for the use of the research plot areas and to the Department of Agricultural Engineering for the equipment made available.

The suggestions, discussions and labor donated by my fellow lab mates - J. Schrieber, J. Gaynor and E. Kuo are greatly appreciated.

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

LIST OF TABLES

DISPOSAL OF DAIRY COW WASTE SLURRIES ON AMITY SILTY CLAY LOAM SOIL

INTRODUCTION

Traditionally, animal wastes have been viewed as a nutrient source or fertilizer for field crops. The disposal of the waste could be handled by the individual operator on his own farm. Livestock operations have now been intensified, with both an increase in cattle per unit area and much larger operating units. In addition, the reduced cost of inorganic commerical fertilizers has reduced animal waste usage as a source of plant nutrients (49). Animal waste disposal, indeed has become a problem of major concern.

There are nearly 300,000 dairy cows in Oregon and Washington with 70% of the cows located in the high rainfall area west of the Cascade Mountain Range. With poor permeability and high rainfall many soils are saturated and often times flooded. Thus, increased surface runoff occurs when animal wastes are applied by modern large sprinklers or manure guns during the high rainfall season.

At what application rates can animal wastes be applied to these wet soils? Can drainage tile be used to drain the soil to reduce potential runoff hazards of surface applied liquid animal wastes? These questions are currently asked by many persons associated with the livestock industry. With these two questions in mind a field study was designed to measure the effect of animal waste application rate and drainage tile on nitrogen and phosphorus content of soils and water.

REVIEW OF LITERATURE

History of Animal Waste Use

Early Roman Agriculturalists advocated the use of manure from birds and domestic livestock to improve crop production (23). During the early Christian era through the Middle Ages, many people wrote articles pertaining to improvement of agriculture with the wise use of animal waste, but because the farmers were illiterate the proposed ideas did not develop extensively.

Early agronomy workers investigated the role of minerals in plant growth. DeSaussure formed the original treatises on practical agriculture, known as the 'organic mold' doctrine. He discovered that carbon served an important role in plant growth. Voight, Thaer and Boussingault supported DeSaussure's 'organic mold' doctrine. These agriculturalists perceived animal and vegetable matter as the only source of plant nutrients. Animal manure was called the most perfect plant food and recognized as mainly a nitrogenous substance.

Plant nutrition and improved soil fertility practices, which included crop rotation, were advanced by Justus Von Liebig, a German organic chemist turned agricultural chemist. Liebig's principle theories dealt with mineral nutrition of plants but he also understood that organic residues and farm manure decomposed in the soil and formed carbonic acid and ammonia. Liebig studied animal manure and its effect on crop rotations of clover, potatoes, wheat and oats. He concluded that nitrogen was added to the soil at a rate of 25 to 30 pounds per acre per year with the addition of manure on a dry weight basis (10).

Animal Waste as a Resource

Animal Waste Constituents

Fresh dairy cow manure may contain anywhere from 30 to 80% water. The remaining 20 to 70% of the waste is comprised of organic and inorganic solids. Roughly, 90% of the dry matter is organic waste from animal digestion of feeds (63).

The nutrient content of animal waste varied with the livestock species (Table 1), and the waste fraction analyzed (Table 2). Nitrogen and K are concentrated in the urine while P, Mg and Ca are concentrated in the feces. The elemental concentrations observed in animal waste products are also subject to the animal metabolism (Table 2).

Many trace elements occur in animal wastes (Table 3). Elements such as Cu, Zn, Fe and Mn are required for plant growth and often must be added to maintain a nutrient balance in soils. Sodium is also required for plant growth.

Table 1. Composition of animal manures (32).

Animal	Moisture (%)	Waste Constituents								
		N	P	K	S	Ca	Fe	Mg	Volatile solids	Fat
		lbs/ton of manure (dry weight)								
Dairy cattle	79	11.2	2.0	10.0	1.0	5.6	0.08	2.2	322	7
Fattening cattle	80	14.0	4.0	9.0	1.7	2.4	0.08	2.0	395	7
Hogs	75	10.0	2.8	7.6	2.7	11.4	0.56	1.6	399	9
Horses	60	13.8	2.0	12.0	1.4	14.7	0.27	2.8	386	6
Sheep	65	28.0	4.2	20.0	1.8	11.7	0.32	3.7	567	14

Table 2. Distribution of waste constituents between urine and feces (17).

Constituent	Dry cow		Milking cow	
	Urine (%)	Feces (%)	Urine (%)	Feces (%)
K_2O	95	5	92	8
Cl	95	5	98	2
Na_2O	74	26	73	27
N	63	37	51	49
SO_4	51	49	44	56
MgO	11	89	12	88
P_2O_5	1	99	2	98
CaO	0	100	1	99

Table 3. Trace elements from beef and dairy wastes (54, 6).

Element	Concentration* (ppm)
Cu	12- 31
Fe	550-1350
Mn	65- 150
Zn	45- 240
Na	770
Cl	1540

*Concentration expressed in material which contains 75% moisture.

Animals excrete organic solids which are subject to degradation and require large amounts of oxygen for biodecomposition. A 1000 pound dairy cow excretes ten pounds of solids per day, equivalent to 1.2 pounds of BOD_5 (Table 4). The biochemical oxygen demand (BOD_5), a measure of biologically degradable material present in organic wastes, is the amount of free oxygen utilized by aerobic organisms when allowed to attack organic residues in an aerobic environment maintained at 20°C for five days. The BOD_5 relationship of 12 to 1 for cattle to man has been established and intensifies the problem of cattle waste disposal (37).

The microbial content also affects the method of animal waste disposal. Coliform bacteria inhabit the lower intestinal tract of warm blooded animals and are in association with pathogenic bacteria, *Salmonella sp*. and *Shigella sp*. Ducks, sheep and humans produce the highest total coliform per gm excrement (Table 5). Proper waste disposal management is necessary to insure that the pathogens associated with the coliform bacteria are not introduced into surface or ground waters.

Animal Waste Uses

Animal wastes can be utilized as feed for ruminant animals. Manure is a valuable source of amino acids and vitamins (Table 6). Washed or dried fresh feed lot manure when blended with corn

Table 4. Animal waste production and chemical analysis (37).

Animal	Animal weight (lbs)	lbs/day			
		Solids	BOD_5	N	P
Beef cow	1000	10.0	1.0	0.3	0.062
Dairy cow	1000	10.0	1.2	0.4	0.062
Swine	100	0.9	0.25	0.06	0.012
Poultry	5	0.06	0.015	0.003	0.002

Table 5. Estimated daily per capita discharge of coliform in animal feces (18).

Source	Moisture content (%)	Fecal discharge (gm/24 hrs)	coliform/gm ($\times 10^6$)	Total coliform ($\times 10^6$/day)
Human	77.0	150	13.0	1950.0
Cow	83.3	23600	0.23	5428.0
Hog	66.7	2700	3.3	8910.0
Sheep	74.4	1130	16.0	18080.0
Ducks	61.0	336	33.0	11088.0
Turkeys	62.0	448	0.29	130.0
Chickens	71.6	182	1.3	237.0

Table 6. Manure constituents important in feed rations (5).

Constituent	Dry matter (%)	Constituent	Dry Matter (mg/l)
Crude protein	4.21	Riboflavin	3.66
Cellulose	46.57	Thiamine	1.06
Ether extract	0.52	Niacin	17.4
Starch	6.57	Pantothenic acid	20.4
Sugar	0.34	Vitamin B_{12}	1.39
Ash	1.68		
Amino acids	7.70		

silage or other feed concentrate, 60 parts silage concentrate to 40 parts manure, proved to be a valuable ration component for economical beef cattle weight gains (5).

Nutrient reclamation from manure disposal lagoons has also been suggested (42). Forage growth in a hydroponic solution of lagoon effluents served to: 1) remove nutrient from waste effluent and; 2) produce forage for cattle consumption.

Animal Waste Disposal Systems

Animal waste disposal systems vary depending upon initial expense for facilities, availability of cleaning water, type of animal housing, and proximity to populated areas. Two disposal systems are commonly used in the livestock industry, biodegradation or lagoon systems and land disposal.

Biodegradation Disposal Systems

Manure lagoons, aerobic and anaerobic, Pasveer oxidation ditches and detention ponds are used in liquid manure systems. Manure lagoons and oxidation ditches reduce liquid manure BOD_5 and total solids content, while the latter has very little biochemical decomposition. Detention ponds are used mainly for temporary manure storage (15).

An anaerobic lagoon operates ideally with slurry depths of 8 to

12 feet, a pH range of 7.2 to 7.4 and a mesophilic temperature range of 59 to 113 °F. Agitation of sludge and raw waste is necessary for proper decomposition. Shock loading, an overwhelming addition of high BOD_5 materials, will cause the lagoon to fail and produce foul odors (39).

Most odors from stored manure result from gaseous emissions of NH_3, H_2S, and trace organic compounds such as amines, mercaptans and skatols (39).

Oxidation ditches and aerobic lagoons both function by aerobic decomposition of liquid animal waste, but differ in the tank design. The oxidation ditch is installed beneath a slotted-floor shed. The ditch consists of a continuous, open channel with an aeration rotor installed to churn and aerate the animal waste.

Aerobic lagoons are generally shallow earthen basins and built so that the animal waste depth does not exceed four feet. Aerobic lagoons do not produce foul odors unless they have become anaerobic. Aerobic lagoons require more lagoon surface area per animal unit and tend to malfunction more readily than anaerobic lagoons.

Reduction of total solids in animal waste slurries can improve liquid manure biodecomposition operations. With less total solids, less residual sludge will accumulate in the digestion tanks. Five systems of liquid-solid separators have been studied (20): 1) the centrisieve is a conical drum lined with filter cloth and rotates at high velocities to fractionally separate the slurry. 2) The decanter centrifuge is a closed cylinder rotating at high revolutions to separate slurries by centrifugal force. 3) Vacuum filters consist of a slow revolving cloth covered drum partially submerged in a slurry tank. An internal vacuum adheres the solids to the cloth. 4) Vibro screen separators oscillate essentrically to remove liquid from solids. 5) The sedimentation silo is a large circular concrete settling basin which utilizes gravity to separate liquids from solids.

Land Disposal Systems

Disposal of animal wastes to land areas can be accomplished through direct application to the soil surface or mechanical application to the subsurface of the soil. Applications of animal wastes to the soil surface requires less equipment than application of waste to the soil subsurface.

Effluents from anaerobic and aerobic lagoons, oxidation ditches and detention ponds can be applied with high capacity sprinklers or manure guns to land surfaces (15). A low-volume, high-head pump is used to supply the effluent through conventional irrigation pipe. Sufficient dilution of the animal wastes is required such that the total solid content does not exceed 8.0%. If the total solid concentration exceeds 8.0%, hydraulic head losses reduce pumping distance markedly (54).

Land disposal of animal waste slurries may also be accomplished by motor driven application units. Subsurface applicators are tractor drawn trailer tanks of 1000 or more gallon capacity. Waste applied by subsurface methods generally contains > 15% solids in the slurry.

Using the subsurface application method, dairy slurries, which contained 12.5% total solids, were applied four inches deep in the soil at rates up to 75 tons of total solids per acre per year (9). After the applications, the soil extractable NO_3-N and salt content increased rapidly. The NO_3-N content of the surface six inches of the silt loam soil increased from 12 to 166 pounds per acre. At the four foot depth the extractable NO_3-N content was 43 pounds per acre. The Na concentrations in the upper foot of the soil surface increased from 1 ppm to 73 ppm after the waste application. At the four foot depth the Na concentration in the soil increased from 1.0 ppm to 27 ppm. The K concentration increased from 1.0 ppm to 115 ppm in the surface foot of soil. While the K concentration at the four foot depth of soil increased from 1.0 to 43 ppm.

Manges et al (33) applied feed lot manure to a corn field at the rates of 48, 74, 123 and 241 tons of dry matter per acre. One year after application, the soil NH_4-N concentration was 45 ppm in the surface one foot of soil after the application of 123 tons per acre. The NO_3-N concentration increased from 3.0 ppm in the untreated soil to 45 ppm in the upper 20 inches of treated soil. The total P concentration increased from 10 ppm in the untreated soil to 463 ppm in the treated soil. The Na and K concentrations in the untreated soil increased from 125 ppm and 230 ppm, respectively, to 150 ppm and 1050 ppm. The applied manure contained 0.2% Na and 1.1% K or 246 and 1350 pounds per acre applied from 123 tons of manure per acre, respectively.

The effect of soil cover on surface water runoff was examined by Robbins et al (47). A barren sandy loam soil with a slope of 2 to 10%, to which 515 tons "wet" poultry wastes per acre were applied had 62 ppm total-N and 265 ppm BOD_5 in the runoff water. When the same soil was grass sod covered and received 4.0 ton per acre application of "wet" poultry wastes the surface runoff water contained 3.5 ppm total-N, 5.2 ppm BOD_5 and 1.2 ppm total-P.

Swanson et al (56) studied the effect of rainfall intensity and duration on the potential pollution from cattle feedlot runoff. Rainfall simulators applied different quantities of water at several intensities to a feedlot surface with an 8.5% slope. A simulated storm of 2.74 inches per hour with durations of 24 to 60 minutes removed 71 to 79 pounds total-N per acre-foot of runoff and 22 to 54 pounds total-P per acre-foot of runoff water for the periods of rainfall duration.

Past recommended application rates have been 20 tons per acre (13). In western Washington Turner and Proctor (60) have recommended liquid manure applications of five acre-inches containing 10.0% total solids or 56 tons of solids per acre applied prior to seeding silage corn. Liquid manure application rates of 45 to 50 tons per acre have been suggested from research at Ottawa, Canada (59).

McCaskey et al (36) at Auburn, Alabama surface applied dairy cow wastes for 21 consecutive months to sod covered plots. Liquid manure rates of 17 tons dry matter per acre per year were recommended with principle concerns being fly and odor control.

Reddell et al (45) applied beef manure at 50% moisture to cultivated fields at 0, 300, 600, and 900 tons per acre per year. The manure was moldboard plowed into a fine sandy loam soil to a depth of 30 inches. The runoff water after the incorporation of 900 tons per acre of manure contained 1700 MPN fecal coliform, 69 ppm NH_4-N and 713 ppm total P. One month later, the runoff water contained 26 ppm NH_4-N, 3.4 ppm total P and 200 MPN fecal coliform. Volunteer weed yields were 5500 pounds dry matter per acre for the control treatment while weed yields decreased to 550 pounds per acre when 900 tons of manure was applied.

Mathers and Stewart (34) applied 0 to 215 tons of "dry" manure at 50% moisture per acre per year for two years to a cultivated field. The manure was plowed to a depth of eight inches. Salt accumulations in the surface soil became a possible problem for the growth of crops at the 215 tons per acre application rate. The soil extract conductivity for the surface eight inches was > 10.0 millimhos per cm. The conductivity decreased to < 2.0 millimhos per cm at the 90 inch soil depth. Soil conductivity of 4.0 millimhos per cm will decrease yields 50% or more for most forage and vegetable crops (58). The soil NO_3-N concentrations increased from 2.0 ppm in untreated soil to 12 ppm at a depth of 12 feet after the application of 108 tons per acre per year for two years and two crops of sorghum.

Nitrogen in Animal Waste

Organic Nitrogen

Dairy cow wastes contain 15 to 20% protein, principally as amino acids, nucleoproteins, proteins and amino sugars. For organic N to become available for further chemical or biochemical reactions as inorganic nitrogen, it must initially undergo a mineralization process.

Mineralization

Organic N mineralization involves microbial degradation processes. The initial process of mineralization, ammonification, involves the release of ammoniacal N from nitrogen containing organic compounds.

Ammonification occurs under a range of soil conditions. The optimum pH for ammonification occurs in the slightly alkaline range, pH 7.0 to 8.0, although due to the heterogenicity of ammonifying organisms, ammonification reactions may occur between pH 4.0 to 9.0 (61). The soil temperature at which ammonification occurs ranges from 50°to 70°F (24). Ammonification may occur at soil moisture contents from field capacity to air dry conditions, the ideal soil moisture content being 5/6 wilting point (48).

Several microorganisms are responsible for transformations of protein N to NH_3, i.e., Bacterium sp., Bacillus sp., Actinomycetes sp. and fungi. These organisms hydrolyze proteins to peptides and peptides to amino acids. Any one or more of five processes can bring about amino acid degradation: 1) Hydrolytic deaminization of an amino acid to form fatty acids and NH_3; 2) Decarboxylation with amine formation to form an alcohol and NH_3; 3) Reductive deaminization by H_2 to form NH_3; 4) Amino acid anaerobic hydrolysis to form NH_3; and 5) Oxidative deaminization to form NH_3.

Inorganic Nitrogen

Ammonia losses from manure applied to fields may be quite high. Soils of high pH, 8.0 to 9.0, and high concentrations of NH_3, such as found in animal urine, enhance NH_3 losses. The urea in the animal urine decomposes in water to form CO_2 and NH_3. From a study which involved microbial decomposition of farm manure, Waksman observed that 31% of the total N present in manure was volatilized as NH_3 (61, 35).

Excreted dairy cow wastes, urine and feces mixed contain approximately 0.2% inorganic N, equivalent to 11 pounds of total -N per ton. Approximately 99% of the inorganic nitrogen present in animal waste occurs as NH_4-N while only 1% of the inorganic nitrogen occurs as NO_3-N (54).

Ammonium Nitrogen Adsorption

Ammonium ions are formed when NH_3 is absorbed by water (14). Different quantities of NH_4^+ ions are adsorbed at different pH levels in a soil system. Pratt and Blair (43) estimated that the cation exchange capacity increased between pH 3.0 and 8.0 for organic matter and clay minerals was 370 meq/100 gm and 15 meq/100 gm, respectively. This increase in cation exchange capacity will increase adsorption of cations such as NH_4^+.

Ammonium Nitrogen Fixation

Several clay minerals have the ability to fix NH_4-N. Vermiculite, illite, montmorillonite and biotite fix NH_4^+ ions due to the geochemical size (1.2A°) and electrocharge of the NH_4^+ ions. Sohn and Peech (53) made additions of anhydrous NH_3 to soil with and without organic matter. The soil was equilibrated overnight and leached with NaCl to remove available NH_4^+. The organic matter influenced the amount of NH_4^+ fixation. The mineral portion of the soil fixed 10 to 90% of the applied NH_4-N.

Wetting and drying cycles increase NH_4-N fixation. A moist sandy loam soil of mixed mineralogy was dried one time and treated with 100 ppm tagged $^{15}NH_4$-N. The non-dried soil fixed 11.0 ppm NH_4^+ while the dried soil fixed 63 ppm NH_4^+. Three drying cycles increased $^{15}NH_4$-N fixation to 77 ppm (28).

Ammonium Nitrogen Movement

Ammonium-nitrogen movement is restricted due to strong adsorption to exchange sites. Nelson (41) cited only three to four inch movement of NH_4^+ ions in a fine sandy loam soil. The N was applied as NH_4NO_3 fertilizer to corn at the rate of 120 pounds of N per acre. Twelve inches of irrigation water were applied during a three week period prior to the determination of the N movement.

Nitrification

Nitrification is a biochemical oxidation of NH_4^+ to NO_3^- ions. Nitrification is performed by two groups of microorganisms, autotrophs and heterotrophs. Heterotropic NH_3 oxidation may include aromatic or aliphatic intermediate products, rather than NO_3^- or

NO_3^- end products as formed by autotrophs.

Autotrophs use the energy derived from oxidation of NH_3 for physiological processes, while heterotrophs squander the energy derived as heat energy. Two autotrophs are mainly responsible for nitrification of NH_3 to NO_3^-. Nitrosommonas sp. oxidize NH_3 to NO_2^- and immediately Nitrobacter sp. oxidizes NO_2^- to NO_3^-.

Nitrification occurs under various soil conditions. A specific soil pH range of 6.5 to 9.5 and a soil temperature range of 25° to 35°C are required for nitrification (2). The optimum soil moisture content for nitrification ranges from 40% of moisture holding capacity, as an upper limit, to 15 bars soil moisture tension or wilting point, as a lower limit. Soil applied manure appears to increase the abundance and activity of the nitrifying organisms by adding a nitrogen source (2).

Nitrate Nitrogen Movement

After the oxidation of NH_4-N to the NO_2-N form, the N may readily leach. Raney (44) found the total amount of percolating water does not affect the total leached NO_3^-, since the ions are leached in the first initial percolated water. This theory was also substantiated by Johnson et al. (29) in a study where tile effluent NO_3-N concentrations and flow rates were measured. The average peak tile effluent NO_3-N concentration occurred with the initial flush of percolated irrigation water. Tile effluent concentration of 25 ppm NO_3-N were measured from split applications of anhydrous NH_3 applied at a rate of 195 pounds of N per acre. The fertilizer was applied to a silty clay soil planted to cotton.

Denitrification

Nitrogen may be lost to the atmosphere in gaseous forms. The common N gas is N_2. The gas occurs during the biochemical or chemical reduction of either the NO_3^- of NO_2^- ions.

Over 80% of NO_3^- or NO_2^- can be denitrified under the following conditions: presence of NO_3^- and organic matter, poor soil aeration (>60% soil water holding capacity) (12), pH > 7.0 and high temperatures, 25° to 60°C. Bremmer and Shaw (11) indicated that KNO_3 added to a soil with a pH > 7.5 in the presence of glucose was denitrified completely after four days at 25°C.

Chemical denitrification does not require an enzymatic system to reduce NO_3^- to a volatile gas. Nitrous acid, NHO_2, is chemically denitrified when soil pH levels are < 5.0, yielding gaseous NO. Nitrous acid also reacts with NH_3 and α-amino acids to produce N_2 (19). Stewart et al. (55) cited that the NO_3-N concentrations in surface soils beneath feed lots contained an average of 70 ppm. The NO_3-N concentration at the 20 foot depth decreased to approximately

5.0 ppm. Control treatments consisted of cultivated dryland fields with NO_3-N concentrations of 10 ppm in the surface, decreasing to 1.0 ppm at 20 feet. A decrease in redox potential of -300 millivolts was noted and this either prevented the formation or chemically reduced the NO_3-N present.

Immobilization

Nitrogen immobilization of inorganic N to organic N by microbiological processes is accomplished when microbes synthesize new tissues from applied N. Succeeding generations utilize disintegrating microbial tissues and a continuous internal cycle is developed, with stabilized humus being the end product (24).

Phosphorus Content of Animal Waste

Inorganic Phosphorus Fixation

An animal waste, which is 80% water, will contain approximately 0.12% total P (35). Approximately 50% of the total P is inorganic orthophosphate. Upon application of the waste product to the soil, the inorganic P fraction will react readily to form relatively insoluble phosphate precipitates.

Soil Texture

Soil texture, as related to clay content, greatly affects the adsorption of P. A sandy loam soil equilibrated with KH_2PO_4 for a 12 to 24 hour period exhibited four times more adsorption than a sandy soil (21).

Closely related to the soil texture is the effect of the clay mineral on P fixation. Fixation of phosphates by silicate minerals is a surface reaction between exposed hydroxyl groups on the mineral crystal and $H_2PO_4^-$ anions. Iron and aluminum hydroxides often coat clay minerals and react readily with phosphate ions to form insoluble iron and aluminum phosphates.

In addition to the simple reaction of the phosphate ion with the clay mineral, organic materials adsorbed to the clay mineral surface also may affect the phosphate fixation reaction. Phosphorus fixation, by kaolinite coated with organic materials, reacts in several stages. Initial sorption of P at low concentrations occurs through anion exchange with an organo-mineral gel surrounding the inorganic soil particles. When higher P concentrations saturate the film with phosphorus, the phosphorus diffuses through the gel to react with the mineral components (16).

Phosphorus Fixation at Low pH

Ions present in the soil determine pH as well as the type of P fixation. The hydrous oxides of Al and Fe are the most important compounds for P fixation at pH levels < 6.0. Hsu (26) studied P fixation with amorphous $Al(OH)_3$ at pH 3.8 to 7.0 and found that the initial fixation reaction was completed in 30 minutes. Phosphorus adsorption with these hydrous oxides follows Freundlich and Langmuir adsorption isotherms (46). Minimum P fixation, although still large for soils, occurs between pH 6.0 and 7.0 (7).

Phosphorus Fixation at High pH

Fixation of inorganic P at pH ranges from 7.0 to 10.0 occurs with the chemical precipitate ion Ca or Mg. Superphosphate applied to limed soils or soils high in pH will be reverted to a hydroxy-apatite similar in characteristics to raw rock phosphate. In work at the Rothamsted Experiment Station, Nagelschmidt and Nixon (40) reported a six fold increase in apatite content in soils which received annual superphosphate application for 65 years.

Organic Phosphorus

Of the total P content in animal wastes, approximately 50% exists as organic P (62). The primary compounds which contain organic P are inositol phosphates with small concentrations of nucleic acids and phospholipids (7).

The organic phosphates are fixed in a manner similar to inorganic phosphates, as insoluble salts of Al, Fe, Ma and Ca. An increase in soil acidity, from pH 1.0 to pH 4.0 increased phosphate fixation markedly due to active Al concentrations (4). Maximum adsorption of inositol hexaphosphate (phytic acid) will occur in low pH montmorillonite systems. Approximately 50% of the applied phytic acid was fixed by montmorillonite at a pH of 4.5 (4).

Movement of Phosphorus Compounds

Phosphorus compounds react rapidly with the soil. Koeliker and Miner (30) applied anaerobic lagoon effluents at four loading rates: 1.5 acre-inch of lagoon effluent when soil moisture levels were at 70% water holding capacity (WHC); 1.5 acre-inch of lagoon effluent when soil moisture levels were at 95% WHC; 3.0 acre-inch of lagoon effluent when soil moisture levels were at 70% WHC; and, 3.0 acre-inch of lagoon effluent when soil moisture levels were at 95% WHC. These rates were applied to a silty clay loam soil over a three month period. The lagoon effluent contained 74 ppm total P and 83% of the total P was removed in the soil surface three inches when surface applied. Ten to 20 pounds of total P were applied in each acre-inch of effluent. Removal of total P from percolating effluent waste continued through the five foot soil profile to the tile drain water which averaged 0.5 ppm or 99% removal of total P. Phosphorus removal by the soil was essentially the same for all application rates.

Animal Waste and Water Quality

The major water pollutants arising from animal wastes are oxygen demanding matter (principally organic materials), plant nutrients such as N and P, and pathogenic microbes.

Soluble P and N can cause euthrophication, an aging process in lakes that includes rampant growth of microflora. Algal blooms are promoted when P concentrations in lakes or ponds exceed 0.01 ppm soluble orthophosphate (50). These algal blooms are undesirable especially for swimming and recreational use because they create an unaesthetic appearance.

Phosphorus can enter surface waters by runoff from cattle feedlots or spread manure in fields, soil runoff and fertilizers. In areas where cattle feedlots are in operation 20 to 40% of the total P entering surface waterways is attributed to animal waste (25). Soil surface runoff water will contain small amounts of soluble P and variable amounts of sediment, depending on the topography, soil type, vegetation, and precipitation intensity. The sediment load may contain as much as 500 to 2000 ppm total P.

Biochemical oxygen demand and bacterial pollution can enter surface waterways in runoff water after storms. Twenty hours after a one-inch rainfall storm, the BOD_5 concentration increased from 2.0 to 90.0 ppm one mile downstream from a cattle feedlot. Fecal coliform count per 100 ml sample also increased from 1150 to 542,000 in the same time period and fecal Streptococcus counts per 100 ml increased from 13,800 to 1,600,000 (52). The additional BOD_5 in the stream decreased the dissolved oxygen level to almost zero. Fish require a minimum dissolved oxygen level of 4.0 ppm.

Domestic water standards of 10 ppm NO_3-N have been enacted by the United States Public Health Service (USPHS). These standards are designed as maximum limits for infants. Ingested water exceeding 10 ppm NO_3-N may cause methemoglobinemia. The infant's intestinal tract bacteria biochemically reduce NO_3^- to NO_2^-. In the presence of NO_2^-, hemoglobin is oxidized to methemoglobin, consequently reducing the oxygen carrying capacity of the blood (51).

MATERIALS AND METHODS

Field Experimental Plots

Winter and Summer 1971

The field study on the disposal of animal wastes was designed to include experimental variables of application rate, tile drainage and vegetative cover. To incorporate the indicated variables twenty-four research plots, each 10 feet wide and 30 feet long, were required.

Twelve plots were desodded, of which six plots were tile drained and six plots had no drainage tile. The 12 remaining plots remained covered with pasture, legume and grass species; six plots with tile drainage and six without a tile drainage system installed.

Dairy cow waste was applied at rates of 0, 30 and 80 tons per acre per year of dry matter to duplicate plots in the sodded, desodded, tiled and undrained plot areas (Table 7).

Field Plot Area

The animal waste field experimental plots were located on Amity silty clay loam of the Oregon Agricultural Experimental farm (Figures 1 and 2). Appendix A.

Table 7. Liquid dairy wastes rates and dates of application rates - dry matter, pounds per acre.

		Medium		High	
Date	Control	Sod	Desod	Sod	Desod
Jan. 1971	0	4700	3100	11750	7750
Feb. 1971	0	1200	3860	3020	9660
Mar. 1971	0	2180	2460	7630	8550
April 1971	0	4760	10900	15090	38100
May 1971	0	960	1015	3040	3180
July 1971*	0	6950	30300	16200	70500
Aug. 1971	0	18600	5820	43450	13600
Sept. 1971	0	15100	7030	35000	16400

*Accumulated dry matter applied during winter application period was removed prior to tile trench tamping.

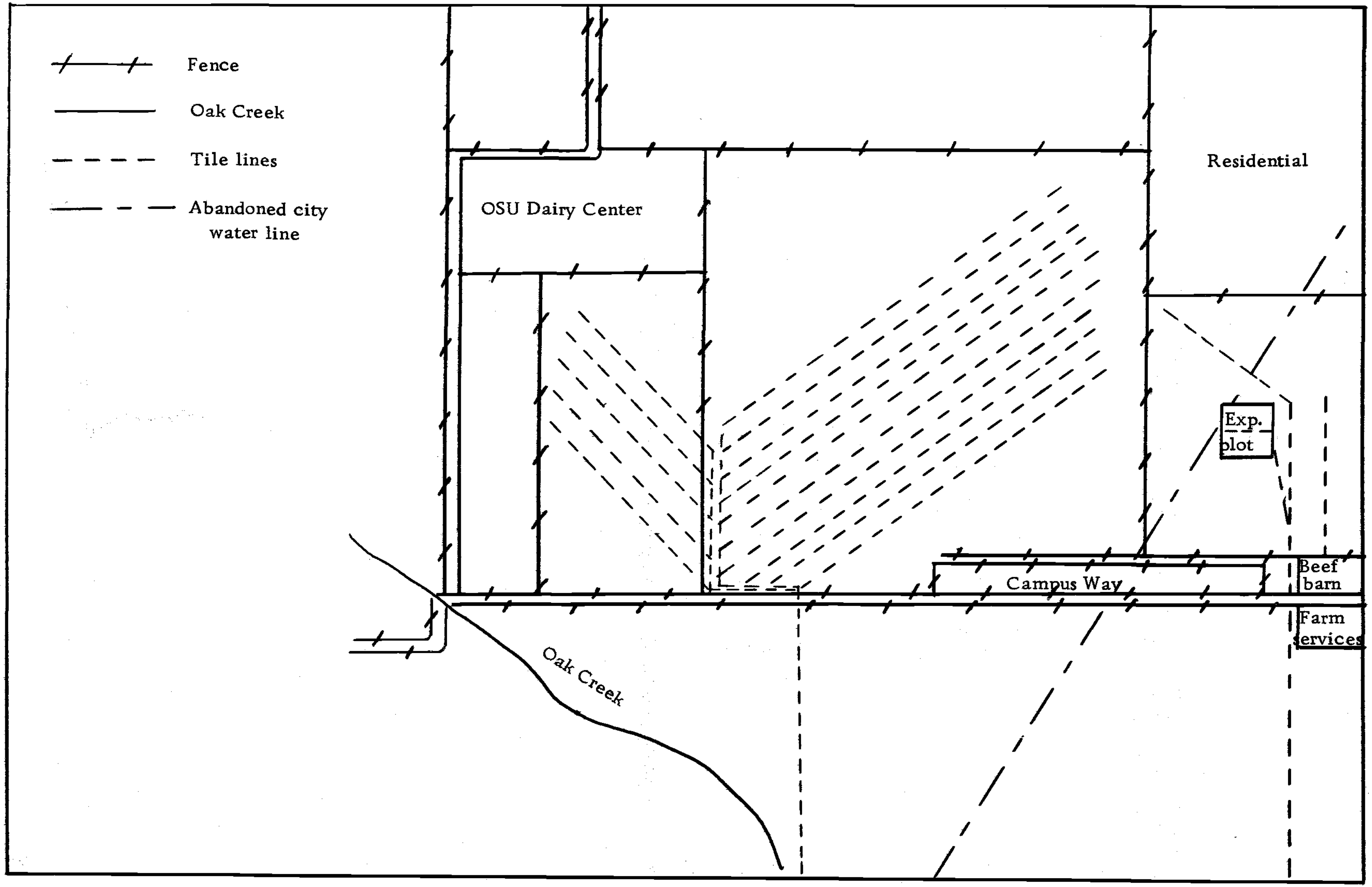


Figure 1. Tile map. (1" = 200')

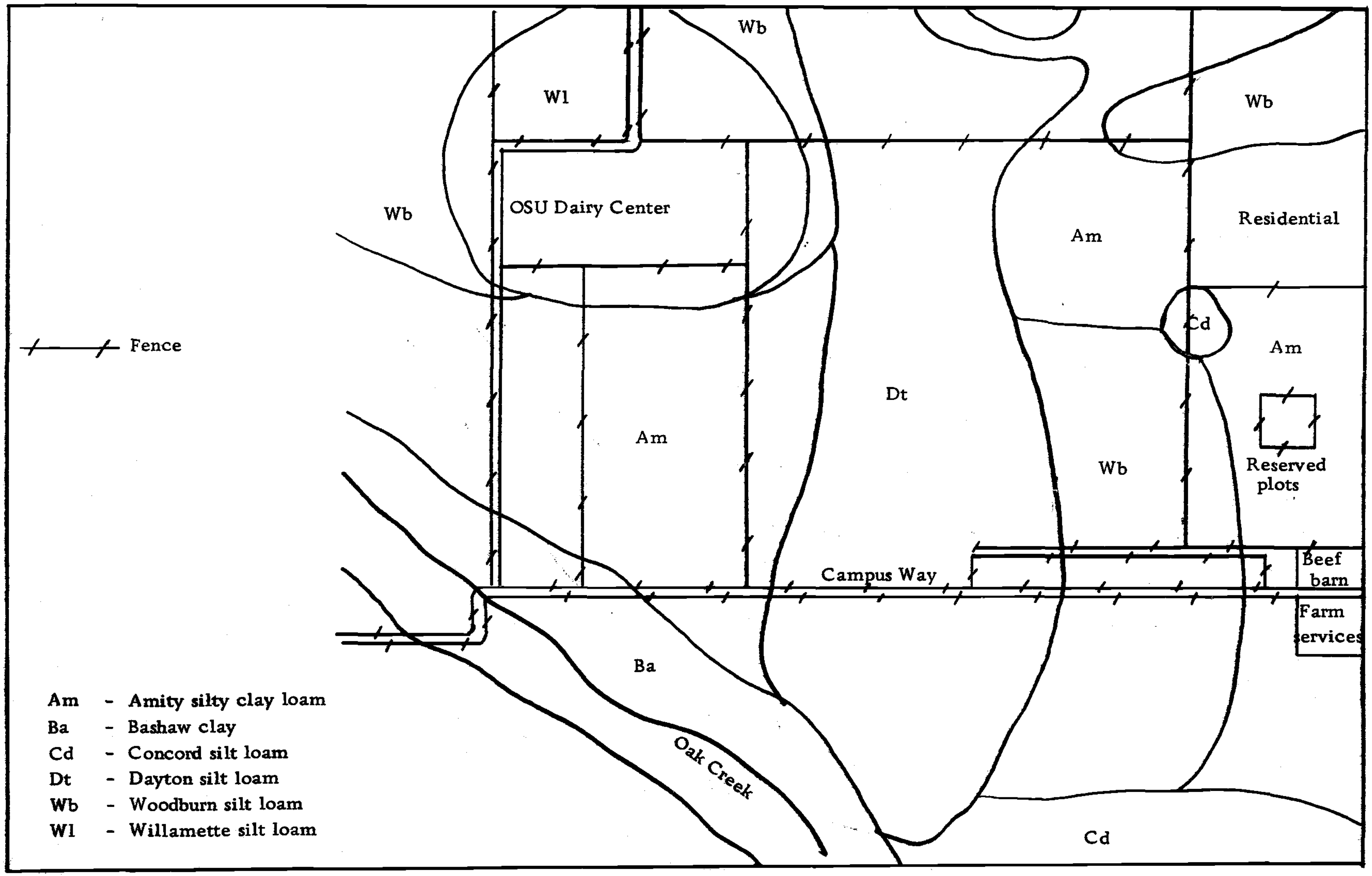


Figure 2. Soils map. (1" = 200')

Plot Construction

The experimental plots were surveyed for tile drainage by Dr. John Wolfe of the Department of Agricultural Engineering. Trench excavation cuts were calculated for two tile trenches within each of the 12 designated tile drained plots (Figure 3). Each plot would contain two tile trenches with a five foot spacing. The main tile line from the laterals and the outlet drainage trench cuts were also surveyed and the cut and fill marks were calculated. The twelve tile drained plots, six on each side of a bisecting main tile line, were installed on a herringbone pattern (Figure 3).

The tile drain trenches and the plastic film barrier trenches around each plot were dug with a "Ditch Witch", self-propelled trench excavator. The tile trenches in the plot were approximately three feet deep, while the plastic barrier trenches around each plot were four feet deep.

The bottom of each tile trench was graded to a 0.6% slope. Pea gravel was used to construct the graded trench floor. The plot drainage tile depth ranged from 28 to 32 inches.

Eight foot sections of two inch, inside diameter, Bermico drainage tile with two rows of 0.38 inch holes six inches apart were placed in the graded tile trenches. Three pipe sections were utilized in each trench. Three feet of undrained space was allowed at each

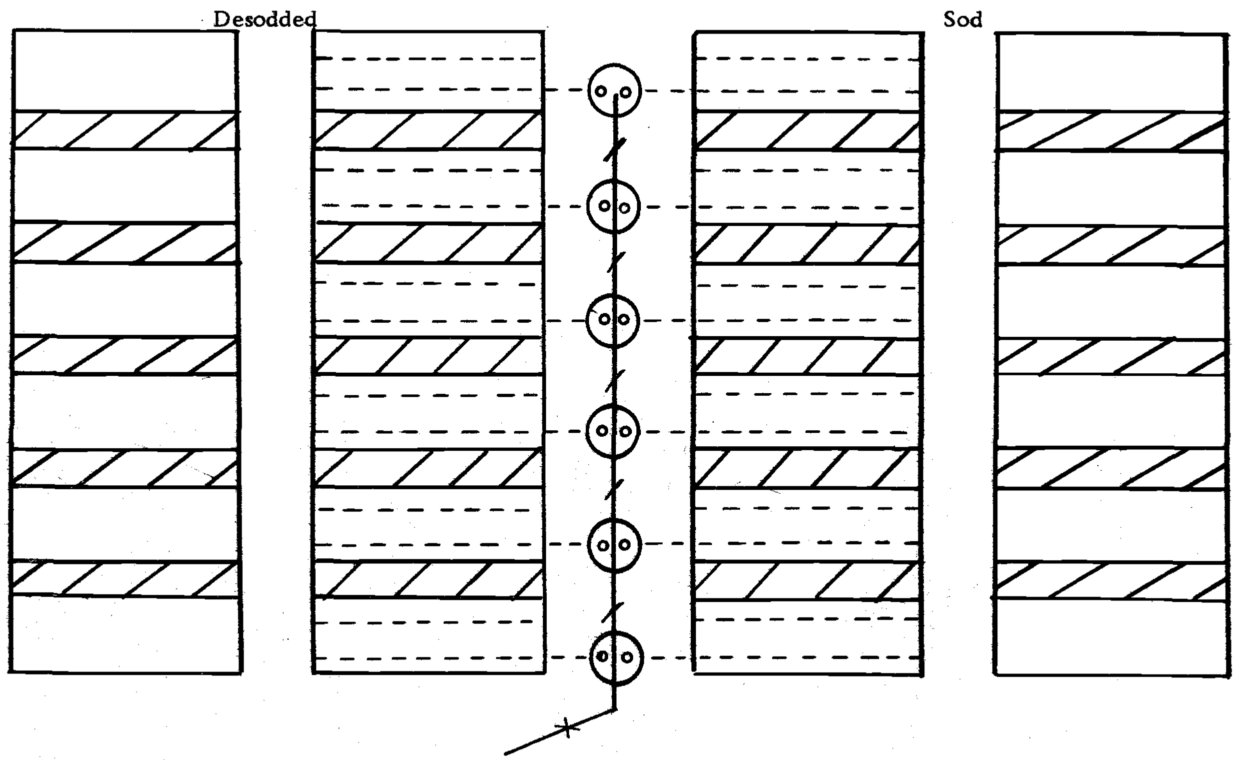


Figure 3. Field plot design for animal waste treatment study. (1" = 20')

end of the tiled plot; therefore, the drain tile underlaid only 24 feet of the 30 feet plot length. Each of the two tile lines in the tile drained plots had a plastic cap placed on the upslope tile pipe end. The down slope tile end was attached to a three feet section of four inch polyvinyl chloride (PVC) pipe. The two tile lines in each plot were joined by a five feet cross connecting section of four inch PVC pipe. A single four inch PVC pipe extended from the tiled plot into a collection sump located over the main tile line (Figure 4).

Collection sumps were constructed from fifty-five gallon oil barrels with inserts cut into the bottom edge of the barrel to fit over the extended plot drainage pipes. Soil was back filled around the barrel sumps.

A four inch main Bermico tile line, perforated with two rows of 0.38 inch holes six inches apart, was installed directly beneath all six collection sumps (Figure 3). The main tile trench was graded with pea gravel on a 0.2% slope. The main tile line transported effluent water from the tile drained plots to an existing drainage system.

Every waste disposal plot was enclosed in six feet wide by 0.004 inch thick clear plastic sheet inserted four feet into the ground. The two feet of plastic sheet which remained above the soil surface was laid over a berm system surrounding each plot to prevent surface runoff. A berm, 12 inches high by 12 inches wide, was

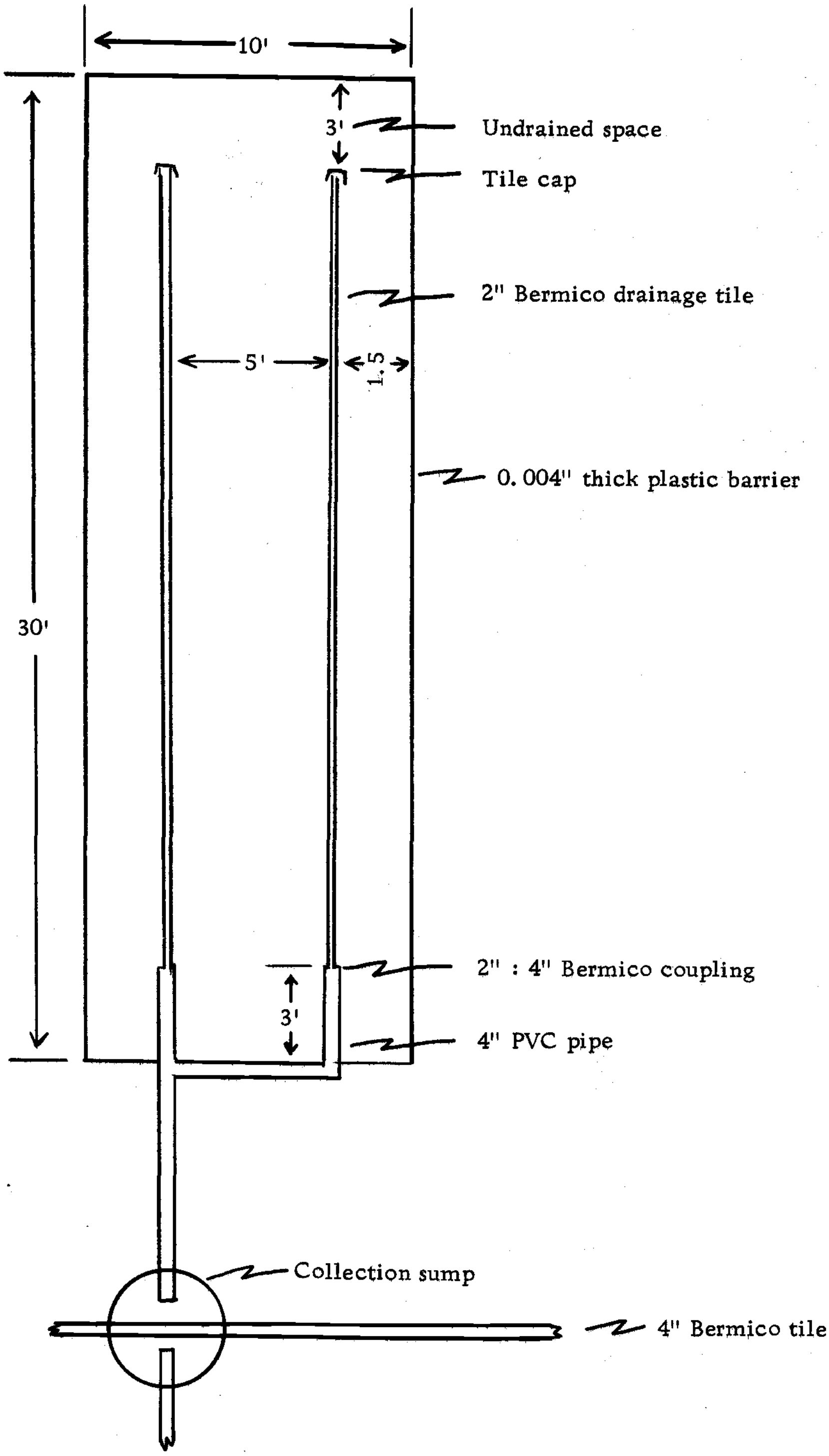


Figure 4. Diagram of plot drainage tile. (1" = 5')

constructed around each plot to retain the bulk quantities of liquid dairy wastes. Excess soil that remained after the trench and back fill operation was used to construct the berms. The underground plastic sheet surrounding the individual plots reduced lateral subsurface water movement into or out of each plot.

After the tile system was installed the sod was removed from the designated plots by a mechanical sod stripping machine. The machine cut sod strips 12 inches wide by two inches thick. The cut sod was rolled and removed from the 12 desodded (barren) plots.

Two ground water sample stations were placed in each undrained plot, one well installed five feet from each plot end and on the longitudinal bisecting axis (Figure 5). A 2.5 inch, inside diameter, by four feet section of plastic pipe, with the lower two feet perforated, was placed in the three feet deep hole prepared with a bucket auger. Soil was firmly packed around the plastic sampling tube to prevent ground water contamination by surface water.

A fence, with a sixteen feet access gate, was installed around the experimental plot area.

Weir System

Orifice weirs were installed on the tile outlets in the collection sumps to measure the rates of effluent water flow from each plot. To construct the weirs a four inch disc was cut from 0.25 inch thick

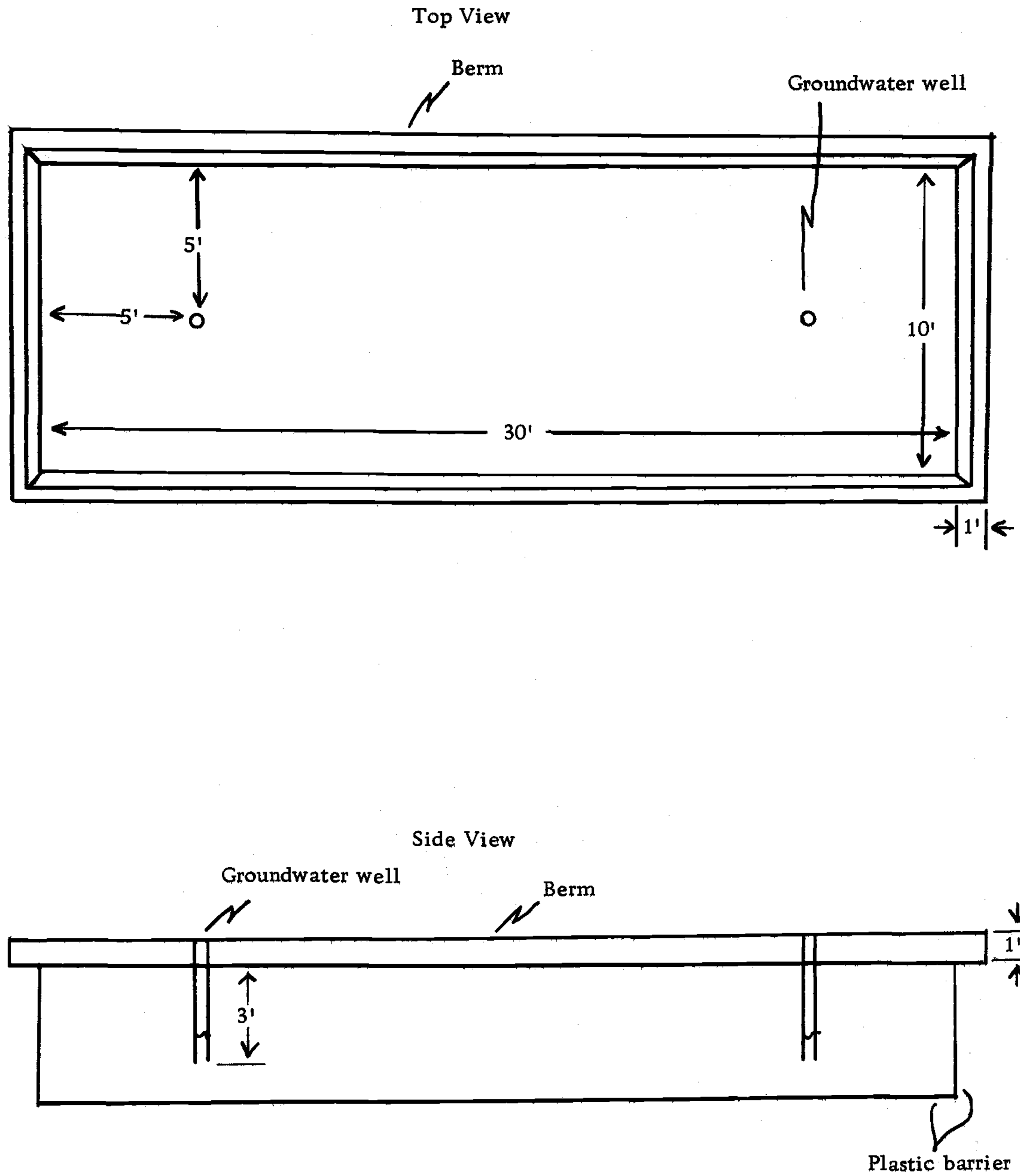


Figure 5. Placement of groundwater wells. (1" = 5')

plexiglas. A 0.19 inch hole was drilled 0.50 inch from the bottom of the disc and counter sunk to give a sharp internal edge for accurate operation. The orifice weir discs were cemented into a ten inch section of four inch PVC pipe which could be attached to the extended tile drain from each plot. A five inch copper tube, 0.063 inch diameter, was inserted vertically into the four inch PVC pipe two inches behind the orifice. A compressed gas escape slot was machined into the tube on the same parallel plane as the weir orifice (Figure 6).

Each orifice weir was calibrated for water flow rates as a function of the hydraulic head prior to installation of the assembly into the drain pipes. Each weir was calibrated by application of known hydraulic heads in a weir calibration tank and measurement of corresponding water flow rates. Calibration curves were plotted for each weir by measuring the volume of water delivered per unit time versus hydraulic head applied.

Hydraulic pressure heads were measured by resistance of compressed N_2 gas escaping from the slotted gas tube. The resistance was measured as inches of hydraulic head in a simple manometer tube.

A control board in the field was prepared to contain two simple manometers, necessary latex rubber tubing to connect each weir with the central manometer board and a small tank of compressed N_2 gas with pressure regulator. The manometer board was installed

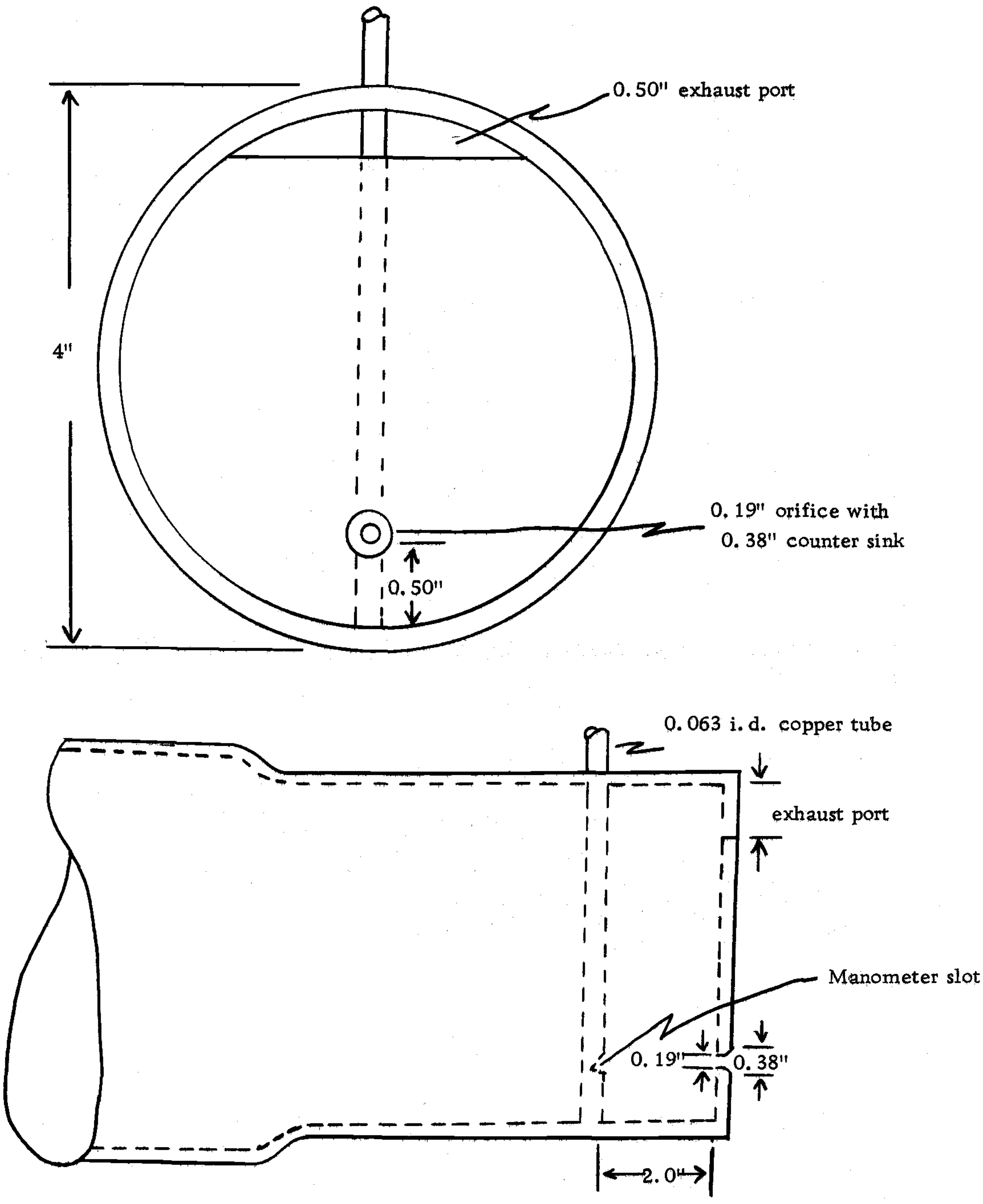


Figure 6. Orifice weir construction.

over the main tile line, midway between the six collection sumps (Figure 7).

Liquid Dairy Waste System

The Oregon State Univeristy Dairy Center's "Ag-Pro" liquid manure system includes a dairy loafing and feed barn with sloped concrete alley ways. Periodically throughout the day, water from storage reservoirs located at the top of the sloped alley ways is released to flush dairy waste, feed, and bedding from the alley ways. The water and waste residue collects at the base of the sloped alley ways in a catch canal and manure tank, with combined capacities of 40,000 gallons. An agitation paddle and centrifugal pump unit removes the animal waste slurry via an aluminum irrigation pipe line to be sprinkled on surrounding fields with a liquid manure gun.

Application of Liquid Dairy Wastes

All liquid dairy wastes which were applied to the research plots were received from the Oregon State University Dairy Center via 1800 feet of three inch diameter aluminum irrigation pipe. Prior to application of the liquid dairy wastes, water was pumped to the research plot area and flow rates were calibrated by recording the time required to fill a 55 gallon oil barrel. Flow rates averaged 150 gallons per minute. After calibration, dairy waste

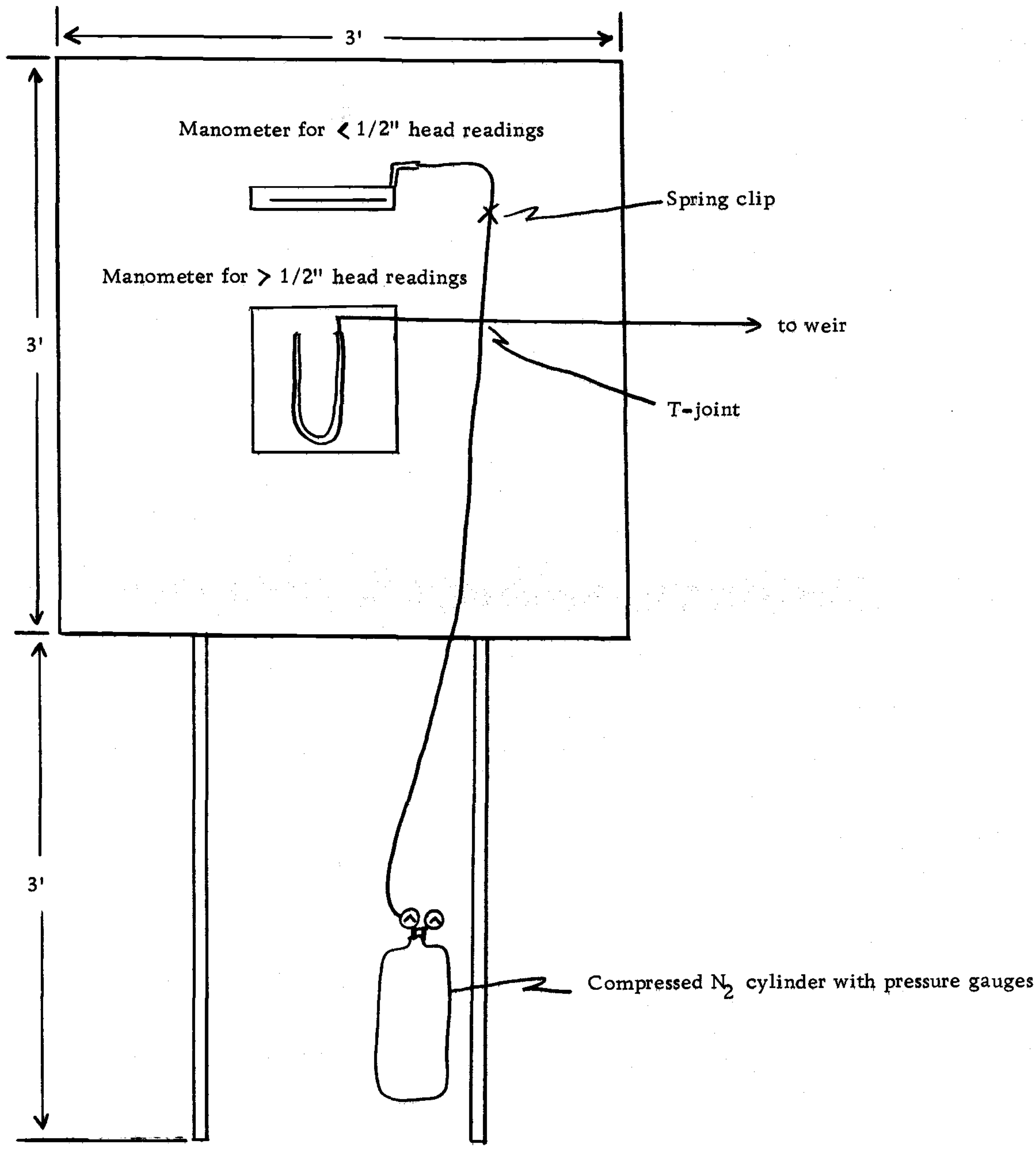


Figure 7. Manometer control board. (1" = 0.75')

slurry applications of 0, 400 and 1000 gallons of waste slurry per plot were applied to the respective plots. A four inch, inside diameter, by fifty feet long rubber lined linen fire hose was used to distribute the animal waste between plots.

The dairy waste was applied every four weeks to the plots during the five month winter application period.

Liquid Dairy Waste Applications After Tile Trench Retamping

The initial application of the animal waste slurries resulted in extremely high effluent flow rates from the tile drained plots. The rapid flow rates were attributed to inadequate tile trench backfills with a resultant "piping" or "channelling" phenomenon. Thus the animal waste flowed immediately into the tile drains, effectively bypassing the soil adsorption system.

To eliminate the problem of selective flow through the backfill, the backfill over the drainage tiles was removed with a portable mechanical trencher. The trencher spoil was piled in the middle of the plot, between the two tile lines. Moisture was added to the excavated soil to facilitate good compaction. Six inches of soil were then repacked over the tile line by the use of a pneumatic tamper. A one inch layer of bentonite was introduced and twleve more inches of moist soil were added and thoroughly tamped. Another one inch layer of bentonite clay was added, followed by aditions of small increments of soil each of which was tamped until the trench was completely refilled. Approximately 100 pounds of bentonite clay was added to 30 feet of tile trench.

Following the retamping operations, liquid waste applications were commenced. The liquid waste was applied at rates of 0, 400 and 1000 gallons per plot every two weeks for the two month summer application period.

Waste Application Frequency Determined by Soil Moisture Criterion

Desodded plots, both tile drained and undrained, were utilized to study soil moisture criteria as affecting dairy slurry application frequencies. The moisture content of the soil was used to determine slurry waste application rates. A saturated soil would have a lower capacity to hold liquid waste products than would a soil at a lower moisture content. A moisture criterion of 0.1 bar tension ($\simeq$field capacity) was utilized as the maximum limit of soil water content. If this moisture limit was exceeded no application of liquid dairy waste would be made.

Three dairy waste application rates were planned for a two week application period. The three application rates were applied in duplicate to six drained and six undrained desodded animal waste treatment plots. Control plots were treated with two acre-inches of irrigation water every two days. A second application rate consisted of one acre-inch of liquid dairy wastes applied each day and utilized the soil moisture criterion. The third application rate was two acre-inches of waste slurry every two days for 14 days regardless of soil moisture content (Table 8).

Moisture tensions were determined by gypsum blocks and tensiometers installed at 12 inch and 30 inch depths (Figure 8). The four moisture sensing units, two gypsum blocks and two tensiometers, were installed in duplicate plots.

Sample Collection

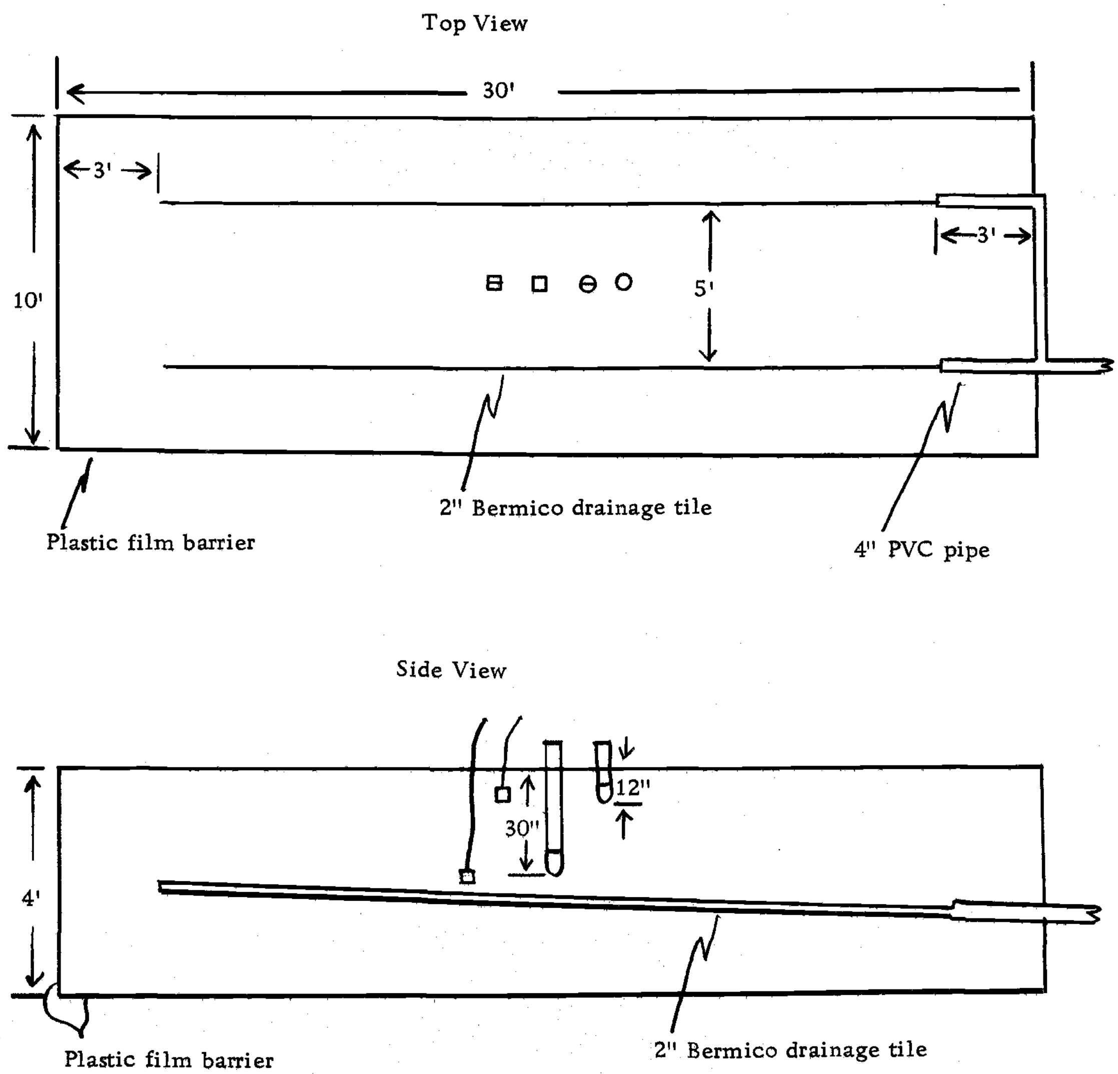
Water Samples

Tile effluent samples were collected as a function of time after every waste application. A dairy waste sample was obtained at the time of waste application. The initial effluent sample was collected from the first visible effluent and further samples were collected at 0. 5 and 1. 0 hour intervals. Drain tile effluents were sampled intermittently after the application day.

Composite ground water samples were collected from the two ground water wells in each undrained plot. Prior to the sampling, each well was pumped dry, except for winter application periods,

Table 8. Dairy waste applications to plots in moisture control study.

Application Date	Dry matter applied (lbs/acre)					
	Control		With moisture criteria		With no moisture criteria	
	Drained	Undrained	Drained	Undrained	Drained	Undrained
10-4-71	0	0	1330	1330	2660	2660
10-5-71			1477	1477	--	--
10-6-71	0	0	1336	1336	2672	2672
10-7-71			1503	1503	--	--
10-8-71	0	0	3172	3172	6345	6345
10-9-71			1325	--	--	--
10-10-71	0	0	1427	--	2854	2854
10-11-71			1523	--	--	--
10-12-71	0	0	2390	2390	5780	5780
10-13-71			869	--	--	--
10-14-71	0	0	1082	--	2165	2165
10-16-71	0	0	706	--	1412	1412
10-17-71			672	672	--	--
Total	0	0	19313	11880	23888	23888



⊟ Gypsum block - 30" deep

□ Gypsum block - 12" deep

⊖ Tensiometer - 30" deep

○ Tensiometer - 12" deep

Figure 8. Placement of moisture sensing devices.

with a converted hand diaphragm pump. All water samples were stored in 150 ml polyethylene bottles at $4^{o}C$.

Soil Samples

Soil samples were collected at 0 to 12 inch and 22 to 28 inch depths at bimonthly sampling periods. The complete Amity sicl soil profile was sampled in July 1970, prior to application of any waste products. Soil samples were air dried, ground to < 2.0 mm and stored in cellophane lined paper bags.

Plot Maintenance

Herbicides were used to control regrowth of grass and legumes on the desodded plots. Paraquat was applied twice, November 1970 and February 1971, at the rate of four pounds active ingredient per acre. A mixture of bromocil and atrazine was applied March 1971 as a short term soil sterilant at the rate of eight pounds active ingredient per acre.

During the summer months, the forage was harvested from the 12 sodded plots with a three foot sickle bar plot harvester. The sod covered plots were harvested at monthly intervals until the first killing frost of autumn.

Animal Waste Applications to Agricultural Tiled Soil

In addition to application of animal wastes to the research area a small study was initiated to investigate the quality of tile drainage waters from an area which had been previously tile drained and to which animal waste had been recently applied.

The pasture, located 200 yards south of the Oregon State University Dairy Center, was tile drained approximately ten years ago. The tile system consisted of four inch clay drainage tiles placed three feet deep on a 62 foot spacing. Since no tile locations maps were filed, the tile drains were located by probing and changes in vegetation.

Sample Equipment Installation

Eight ceramic cup sampling tubes were constructed from four foot sections of polyethylene plastic pipe, 1.5 inches i.e., ceramic cups and rubber tubing. The ceramic cups were fitted to one end of the polyethylene plastic pipe. A size #9 rubber stopper with extending glass and rubber tubing was fitted to the other end of the polyethylene plastic pipe (Figure 9).

Four of the sampling tubes were installed along the tile line on 31 feet centers. Each sampling cup was 2.5 feet deep and one foot off set from the tile line. Additional sampling tubes were

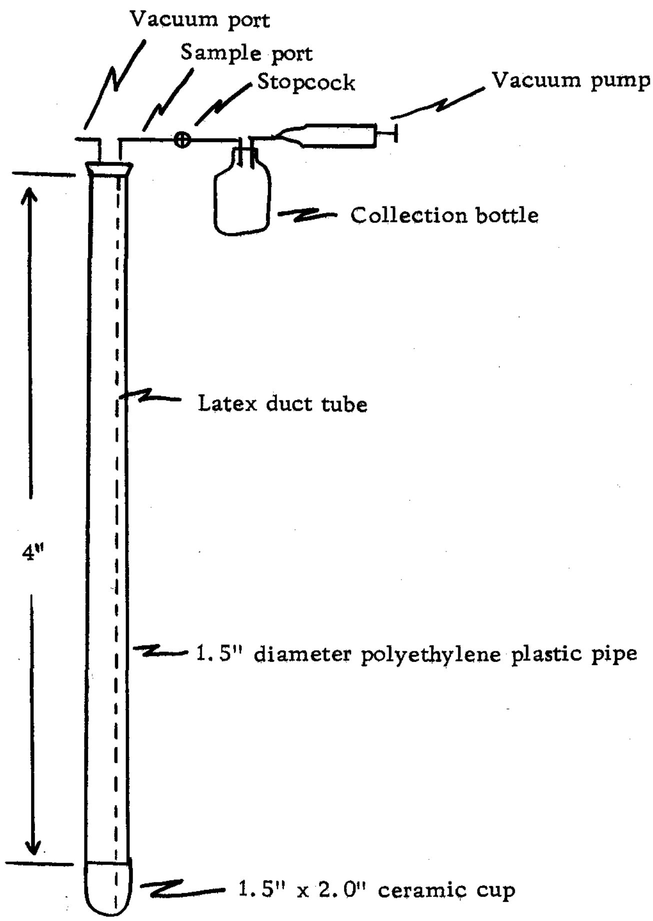


Figure 9. Groundwater sampling tube.

installed perpendicular to the base tile line, two midway between the lateral tile line and two located directly beside the adjacent lateral tile lines (Figure 10).

Liquid dairy wastes were applied by a manure gun. The acre-inches of applied material were determined by measuring the depth of waste collected in two small rain gauges at each sampling tube. Two to four acre-inches of liquid dairy wastes each day for eight days were applied to the sampling area, or 12 tons per acre of total dry matter.

Sample Collection From Ceramic Cups

A hand vacuum pump was used to withdraw ground water samples through the sample port to an in-line collection bottle. After the water sample was removed from the sampling tube, the hand vacuum pump was attached to the vacuum port tube and the sampling tube was evacuated to enable collection of the next sample (Figure 9).

Ground water sampling began 24 January 1972 and animal waste applications began 26 January 1972. In the initial experimental series only one waste treatment could be applied because cold, subfreezing weather froze the liquid flush system and waste delivery pipes for approximately two weeks. Samples were collected for three days following the one application. On 13 February the application of dairy waste slurries resumed for seven days. Ground water

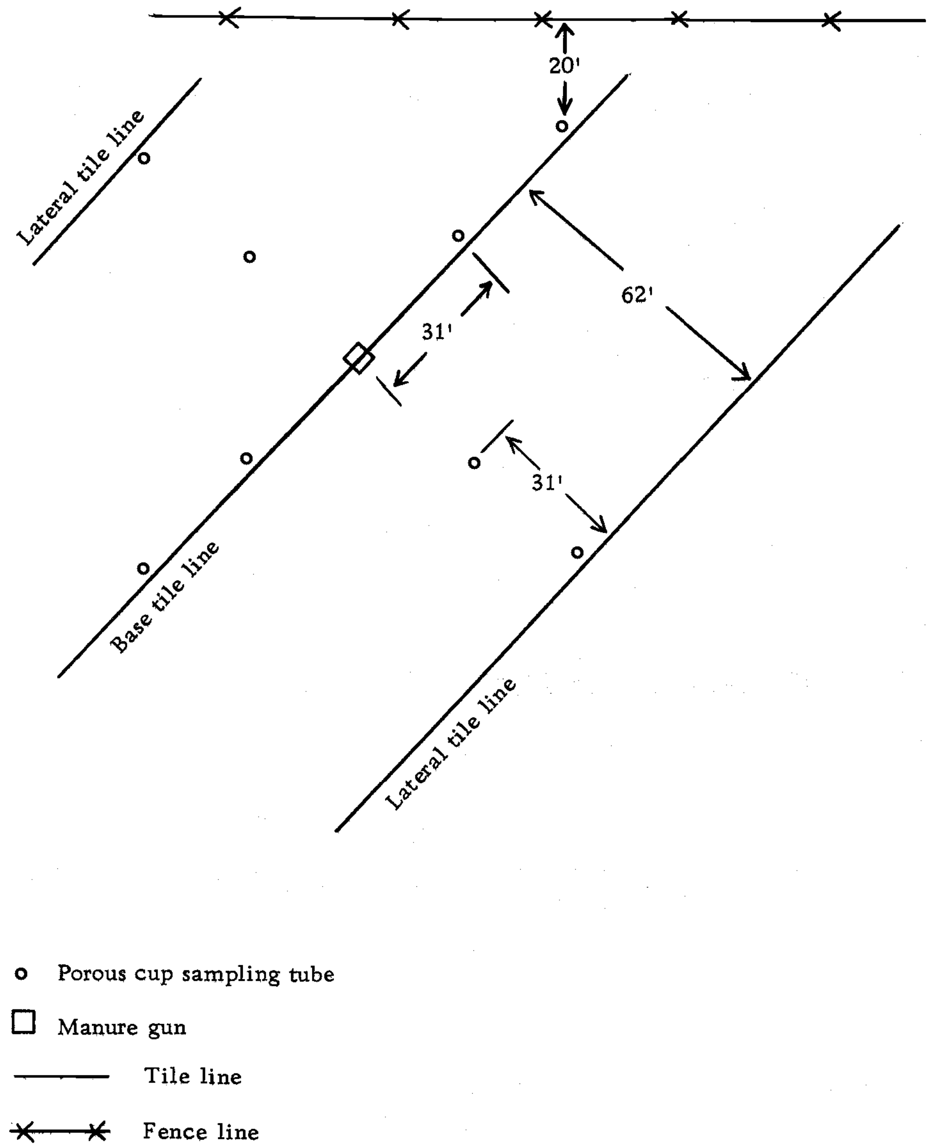


Figure 10. Location of porous cup sampling tubes.

sampling resumed 14 February and continued four days past the 19 February application.

Soil samples were collected 25 February 1972 at three depths, 0 to 6 inches, 12 to 18 inches and 22 to 28 inches, at two sites along the base tile line and two sites midway between lateral tile lines.

Laboratory Analysis Procedures

Liquid Sample Analysis

Total Nitrogen

Total N for both liquid dairy wastes and water was determined by micro-kjeldahl methods (3). A 20 ml aliquot of liquid dairy wastes or water was digested in a 100 ml micro-kjeldahl flask with 20 ml of a concentrated $H_2SO_4Hg SO_4$ K_2SO_4 solution. Samples were digested for approximately one hour.

Digested samples were cooled for 10 minutes and 20 ml of distilled water was added. The digested sample was quantitatively transferred to a micro-kjeldahl distillation unit and 10.0 ml of 40% NaOH was slowly added to the digested sample. One to two drops of phenolphtalein indicator dye was added.

Approximately 75 ml of distillate was collected in a 125 ml Erlenmeyer flask which contained 20 ml of H_3BO_4 mixed indicator solution. The indicator solution contained 40gH_3BO_4, 40 ml bromocresol green-methyl red indicator solution and 400 ml of ethanol per 2.1l of solution. The distillate was titrated with standard 0.005 N HCl acid to a light pink end point. Total N was calculated by the following formula:

$$\text{Total-N}\,\mu g\,/ml = \frac{(\text{sample-blank})\text{ ml acid} \times 0.005\text{ meq/ml} \times 14 \times 1000}{20\text{ ml aliquot}}$$

Ammonium and Nitrate Nitrogen Compounds

Ammonium-N and NO_3-N were also determined by a micro-kjeldahl procedure (46). A 20 ml aliquot of the water or liquid dairy waste sample was transferred to the distillation chamber of the micro-kjeldahl unit.

Ammonium-N and NO_3-N were fractionally distilled by adding 0.2 MgO for the distillation of NH_3. Devarda's alloy, 0.2 g, was added for the distillation of NO_3-N. Each fractional distillate was collected in a separate Erlenmeyer flask containing 10 ml of the H_3BO_4 mixed indicator solution. The distillate was titrated with a standard 0.005 N HCl acid to a light pink color and NH_3-N and NO_3-N were calculated.

Total Phosphorus

The total P content of the liquid dairy waste and water samples was determined by the vanadomolybdate yellow colorimetric procedure after a digestion with $HClO_4$ and HNO_3 (27).

A 50 ml unfiltered aliquot of the liquid sample was pipetted into a 125 ml Erlenmeyer flask and 10 ml of concentrated HNO_3 acid was added. The sample was heated at 160°C until NO fumes evolved. The partially digested samples were removed from the heat and 5.0 ml of 70% $HClO_4$ acid was added to complete digestion. Digestion continued five minutes past evolution of white $HClO_4$ acid vapors. Digested samples were filtered through #50 Whatman filter paper into a 50 ml volumetric flask.

Ammonium vanadate and NH_4MoO_4, 5.0 ml of each, were dispensed into a 50 ml volumetric flask. Aliquots of the digested samples were pipetted into the 50 ml volumetric flasks. The flasks were brought to volume with distilled water. Colorimetric analysis was performed with a Bausch-Lomb Spectronic 20 spectrophotometer at 420 μm.

Soil Sample Analysis

Total Nitrogen

Soil total N was determined by a micro-kjeldahl digestion and distillation procedure. Soil samples, 3.0 gm, were weighed into 100 ml micro-kjeldahl digestion flasks. A digestion accelerator, 2.5 gm, containing Na_2SO_4, $CuSO_4$ and Se metal in a 10:2.5:1 ratio, respectively, and 10.0 ml of concentrated H_2SO_4 was added. Samples were digested for approximately one hour (46).

The digested sample was cooled and diluted with 100 ml of distilled water and quantitatively transferred to a 300 ml distillation flask. Thirty ml of 40% NaOH were added to the digested sample. Approximately 75 ml of sample were steam distilled into a 125 ml Erlenmeyer flask containing 10.0 ml of the H_3BO_4 mixed indicator solution.

The distillate was titrated with standard 0.100 N HCl to a light pink color and total N content of the sample calculated.

Ammonium and Nitrate Nitrogen Compounds

Soil NH_4-N and NO_3-N were also determined by micro-kjeldahl procedures. Fifty ml of 2.0 N KCl solution was added to a 100 ml wide mouth bottle which contained a 10.0 g soil sample. The sample was shaken on a mechanical table shaker for one hour, filtered and the filtrate stored in a refrigerator at 4^oC.

Ammonium-N and NO_3-N analysis, as previously noted, was performed on the soil extracts.

Total Phosphorus

The total P content of the soil samples was determined by a $HClO_4$ digest and vanadomolybdate colorimetric procedure.

A 2.0 g soil sample, particle size <0.5 mm, was weighed into a 250 ml Erlenmeyer flask. Thirty ml of 70% $HClO_4$ were added to the soil and digested at 130°C until the solution appeared clear or after 45 to 60 minutes. The soil did not contain sufficiently high amounts of organic matter, < 5%, to require concentrated HNO_3 for a predigestion (27).

After cooling, 50 ml of distilled water was added. The digested solution was filtered through #50 Whatman filter paper into a 250 ml volumetric flask and the P analyzed by the vanadomolybdate yellow procedure.

Dry Matter Determination

Total dry solids were determined on the liquid dairy wastes. A small porcelein evaporating dish was oven dried, 105°C, weighed and 50 ml of liquid dairy waste was added to the dish (3). The dish and contents were reweighed and placed into the drying oven for 24 hours at 105°C. The evaporating dish and solids were weighed and percent solids calculated.

RESULTS AND DISCUSSION

Characterization of Dairy Cow Waste Slurries

The dairy cow waste slurries were characterized for total solids, total -N and total P, NH_4-N, NO_3-N, water soluble orthophosphate, and BOD_5 levels.

The liquid waste constituents which were applied to the soil varied from month to month (Tables 9, 10, 11, 12). The total solid content ranged from a low of 0.22% on 27 May 1971 to a high of 3.43% on 16 July 1971. The total -N concentration of the waste slurry ranged from 92 ppm on 27 May 1971 to 470 ppm on 8 October 1971. The NH_4-N concentration ranged from 40% to 60% of the total -N throughout the year.

The total -P concentration of the waste slurry remained relatively high for both the summer and fall 1971 application periods with the highest concentration exceeding 500 ppm on 16 July 1971. The total -P content generally ranged from 150 ppm and 250 ppm. The water soluble orthophosphate concentration ranged from 60% to 80% of the total -P concentrations.

The BOD_5 level of the waste remained high throughout the study period. The BOD_5 levels ranged from 300 to 1600 ppm for the one year application period.

Table 9. Characterization of dairy cow wastes slurries applied during winter of 1971.

Application date	Total solids (%)	Total N (ppm)	NH_4-N (ppm)	NO_3-N (ppm)	Total P (ppm)	Ortho P (ppm)	BOD_5* (ppm)
Jan. 1971	0.81	304	102	0.3	84	71	1610
Feb. 1971	0.53	176	83	2.2	76	64	815
Mar. 1971	0.55	253	99	0.5	114	96	1400
April 1971	1.07	236	77	1.4	186	156	960
May 1971	0.27	92	29	1.7	88	70	330

*Analysis performed by Dr. M. G. Cropsey, co-project leader.

Table 10. Characterization of dairy cow waste slurries applied in the summer of 1971.

Application date	Total solids (%)	Total N (ppm)	NH_4-N (ppm)	NO_3-N (ppm)	Total P (ppm)	Ortho P (ppm)	BOD_5* (ppm)
7-16-71	3.43	504	258	3.0	520	328	750
8-5-71	1.57	363	204	1.4	350	220	1240
8-19-71	0.68	308	216	0.4	162	102	1015
9-2-71	2.03	483	200	0.9	232	146	720

*Analysis performed by Dr. M. G. Cropsey, co-project leader.

Table 11. Characterization of dairy cow waste slurries applied in the fall of 1971.

Application date	Total solids (%)	Total N (ppm)	NH_4-N (ppm)	NO_3-N (ppm)	Total P (ppm)	Ortho P (ppm)	BOD_5* (ppm)
10-4-71	0.73	371	225	1.2	175	110	995
10-5-71	0.82	338	204	1.4	155	124	1120
10-6-71	0.74	332	175	1.7	275	173	1230
10-7-71	0.83	413	205	0.3	225	180	1520
10-8-71	1.75	470	300	1.2	285	228	1425
10-9-71	0.73	376	218	0.3	265	212	585
10-10-71	0.79	445	235	3.6	325	260	1380
10-11-71	0.84	329	104	0.1	175	140	530
10-12-71	1.00	339	168	20.1	175	135	1310
10-13-71	0.48	363	219	1.0	235	188	905
10-14-71	0.60	428	215	0.8	230	184	840
10-16-71	0.39	315	172	1.1	180	144	365
10-17-71	0.37	375	229	1.4	215	172	840

*Analysis performed by Dr. M. G. Cropsey, co-project leader.

Table 12. Characterization of dairy cow waste slurries applied in the winter of 1972.

Application date	Total solids (%)	Total N (ppm)	NH_4-N (ppm)	NO_3-N (ppm)	Total P (ppm)	Ortho P (ppm)	BOD_5* (ppm)
1-26-72	1.34	420	195	1.5	182	120	1340
2-13-72	0.68	420	198	0.5	210	168	1250
2-14-72	0.92	436	192	1.0	162	130	920
2-15-72	1.37	390	210	0.6	180	140	1370
2-16-72	0.58	420	180	2.4	165	132	1455
2-17-72	0.48	425	178	0.6	190	152	1090
2-18-72	0.58	420	202	2.0	150	128	1560
2-19-72	0.51	415	195	0.6	134	101	1330

*Analysis performed by Dr. M. G. Cropsey, co-project leader.

Several factors may have affected the animal waste N, P, total solids and BOD_5 concentration during the application year. The waste slurries contained in the detention tank were diluted by varying amounts of water contributed by winter rainfall and from barn alley-way flushing operations. During the winter months the dairy cows were housed in the loafing barn and the alley-ways were flushed two to three times per day. During the summer months, the alley-way flushing frequency was reduced to once daily as the cows were grazing on pasture during the day and housed only at night. Generally the total solids, BOD_5, N, and P concentration of the dairy waste was lower during the winter months as contrasted to the summer months.

In addition to the increased dilution of the waste during the winter months, the elemental content of the waste may be affected by dietary changes in the feeding program. The diet variance affects the manure composition with respect to N and P content. Milk cows excrete approximately 70% of the N and 63% of the P that is consumed in the feed (38). The major winter ration constituents included dent corn silage which contains 0.17% N and 0.07% P and alfalfa hay which contains 2.4% N and 6.24% P. The major ration constituents for summer were grass-legume pasture which contained 0.40% N and 0.10% P and alfalfa hay (38). The summer ration probably included slightly more N and P, thus also enhancing N and P concentrations in the waste slurries during the summer months.

To compare the "wet" manure characterization by Staley (54) with dairy cow waste slurries, a dilution factor must be considered. The dilution factor was determined by comparing the average total solid concentration of the waste slurries and "wet" manure. The total solid concentration of "wet" manure approximated 22%, while the average dairy cow waste slurry concentration approximated 1% (Tables 9, 10, 11, 12, 13). Therefore, liquid dairy cow waste slurries were approximately 22 times more dilute than "wet" manure.

Upon consideration of the 22 fold dilution factor because of moisture differences, one finds that the total -N and BOD_5 content of the dairy cow waste slurry exceeded the total -N and BOD_5 content of the manure by a factor of two. The total P concentration of the dairy cow waste slurry exceeded the "wet" manure by a ten fold factor. These concentration differences were calculated after consideration of the dilution factor of 22 and an average total N and total P concentration in the waste slurry of 400 ppm and 160 ppm respectively.

Animal Waste Applications During Winter of 1971

Dry matter accumulation on the sod covered plots totaled 7.0 and 20.0 tons per acre for the waste treatments during the winter

Table 13. Properties of dairy cow manure (54).

Constituent	Concentration ppm
Total solids	225,600
BOD_5	21,500
NH_4-N	1,900
Organic-N	1,600
NO_3-N	18
Ortho-Phosphate	160
Total P	370

months (Table 14). The desodded plots received slightly more dry matter; 11 and 34 tons per acre, respectively. The desodded plots accumulated more dry matter than did the sod covered plots simply because waste applications were made on different days and with waste of a different total solids content.

After the slurries were applied, 3.0 and 8.0 inches for the medium and high application rates, respectively, were ponded on the surface. The waste slurries remained on the soil surface for two and four hours after the medium and high waste application rates were made to the tile drained plots. Waste slurries applied to the undrained plots remained ponded for a week or more dependent upon rainfall.

The total N applied to the sod covered plots which received the medium and high application rates exceeded 500 and 1300 pounds per acre, respectively (Table 14). Ammonium -N comprised approximately 50% of the total -N applied. Very small quantities of NO_3-N were applied, two to nine pounds per acre. Approximately the same quantity of total -N, NH_4-N and NO_3-N were applied to the desodded and sod covered soil plots.

The total P applied to the plots was very similar for both cover treatments; approximately 300 and 800 pounds total P per acre for the medium and high application rates, respectively (Table 14).

Table 14. Winter application of dairy waste solids, nitrogen and phosphorus to Amity soil.

Application date	Nitrogen applied						Phosphorous applied		Dry matter applied	
	Total-N		NH_4-N		NO_3-N		Total-P			
	lbs/acre									
Sod	A*	B	A	B	A	B	A	B	A	B
1-7-71	109	273	50	124	0.1	0.4	28	70	4700	11700
2-4-71	63	157	30	76	1.3	3.1	35	88	1200	3020
3-4-71	126	314	50	126	0.3	1.2	58	146	2180	7600
4-1-71	81	203	30	76	0.0	0.1	48	120	2900	10100
4-29-71	114	286	38	94	0.8	2.4	90	225	1870	4930
5-27-71	43	109	14	34	0.6	1.7	43	109	960	3040
Total	536	1342	212	530	3.1	8.9	302	758	13810	40390
Desodded										
1-21-71	265	460	49	123	0.1	0.4	53	132	3100	7750
2-18-71	106	270	49	123	0.7	2.0	38	95	3860	9650
3-16-71	118	296	46	115	0.0	0.1	52	130	2450	8550
4-15-71	146	367	44	109	0.7	1.7	130	326	10900	38200
5-27-71	46	115	14	35	1.0	2.5	42	105	1010	3190
Total	681	1508	202	505	2.5	6.7	315	788	21320	67340

*A = 400 gal/plot application rate.
B = 1000 gal/plot application rate.

Drain Tile Effluent

Effluent Flow Rate

Attempts to measure the tile effluent flow rate by the installed weir system proved unsatisfactory because of excessive water flow rates. The weir system was designed to measure 720 and 840 ml per minute water flow rates, but with the high application rates of dairy waste, flow rates of 5600 ml per minute were obtained. The high water flow rates from the tiled plots resulted from the high hydraulic conductivity of the soil and hydraulic heads of the waste slurry on the plot surface. The hydraulic conductivity of the Amity sicl has been measured and varied from 1.8 to 6.4 acre-inches per hours (62).

A factor that compounded the effect of the hydraulic conductivity on the tile effluent flow rates was the internal channelling of the tile trench backfill. Nonuniform compaction and settling of the tile trench backfill created large channels which led almost directly to the drain tile line. When the waste slurry was applied, the slurry flowed through the channels to the drain tile.

Tile Effluent Constituents

The NH_4-N concentration in the tile effluent from the sod covered plots which received the high waste application ranged from 10.0 to 30.0 ppm with only one exception (Table 15). The NH_4-N concentration in the title effluent from plots which received the medium waste application rate were generally about one-half of the NH_4-N level in the drainage waters from the plots which received the high waste application rate. The NH_4-N content of the effluent varied roughly with the concentration of NH_4-N in the applied waste. Less dilution by the water in the soil prior to application of the waste slurry occurred when the smaller waste quantities were applied. The NH_4-N concentration in the tile effluent from control plots were < 1.0 ppm throughout the application period (Table 15).

The NH_4-N concentration in the tile effluent from the desodded and sod covered plots were similar (Tables 15 and 16). The tile effluent NH_4-N concentrations from the desodded plots receiving the high dairy waste application rate ranged from 7.1 to 45.6 ppm (Table 16). The NH_4-N concentration of the tile effluent, three weeks after the waste application date, was generally below 10 ppm (Table 16). These tile drainage waters resulted from rainfall, with the low NH_4-H indicative of NH_4^+ adsorption by the soil.

The initial drain tile effluent NH_4-N concentration reflected both the tile backfill compaction problems and the dilution of the infiltrated waste slurries by soil stored rain water. The internal

Table 15. NH_4-N concentrations in tile effluent from sod covered Amity sicl soil receiving dairy waste slurries.

Application date	Treatment rate (gal/plot)	NH_4-N Applied (ppm)	NH_4-N Effluent* (ppm)	NH_4-N Removed (%)	NH_4-N** [3 weeks] (ppm)
1-7-71	0	0	1.0	--	0
	400	103	69.0	33.0	1
	1000	103	I. S.		1
2-4-71	0	0	1.0	--	0
	400	63	9.0	87.0	0
	1000	63	18.5	71.0	0
3-4-71	0	0	0.0	--	1
	400	104	17.0	84.0	0
	1000	104	22.0	79.0	0
4-1-71	0	0	0.0	--	0
	400	63	16.0	75.0	0
	1000	63	30.0	56.0	1
4-29-71	0	0	1.0	--	
	400	78	23.0	72.0	
	1000	78	22.0	72.0	
5-27-71	0	0	0.0	--	1
	400	28	5.0	83.0	0
	1000	28	10.0	65.0	2

*Average NH_4-N concentration in samples collected within three hours of waste application.

**Average NH_4-N concentrations in samples collected three weeks after the waste application.

I. S. - Insufficient sample.

Table 16. NH_4-N concentrations in tile drain effluent from desodded plots receiving dairy waste slurries.

Application date	Treatment rate (gal/plot)	NH_4-N Applied (ppm)	NH_4-N Effluent* (ppm)	NH_4-N Removed (%)	NH_4-N** [3 weeks] (ppm)
1-21-71	0	0	2	--	0
	400	101	32	69	0
	1000	101	46	55	1
2-18-71	0	0	0	--	0
	400	103	13	87	1
	1000	103	23	77	1
3-16-71	0	0	1	--	0
	400	95	19	80	1
	1000	95	31	67	2
4-15-71	0	0	0	--	0
	400	90	6	94	7
	1000	90	18	80	2
5-27-71	0	0	2	--	0
	400	29	5	82	0
	1000	29	7	76	1

*Average of NH_4-N concentration in samples collected within three hours of waste application.

**Average NH_4-N concentration in samples collected three weeks after waste application.

erosion of the backfill allowed development of preferential water flow channels and eliminated contact between the dairy waste and the soil colloids. Thus, much of the NH_4-N in the applied waste was not adsorbed by the soil, but rather passed through the soil profile and into the drain tile.

Dilution of the waste applied to a soil by the soil moisture present must be considered to accurately evaluate the NH_4-N filtration capacity of the soil. Approximately one acre-inch of water will bring four inches of an air dry clay loam soil to field capacity. After a soil is at field capacity additional increments of water will pass through the soil profile and into lower stratum or tile drains. Rainfall amounting to as little as 5.5 inches per month or between application treatments would be sufficient to percolate the mobile waste constituents through the soil profile. Initially applied waste slurries would be diluted as the waste percolation front percolated through the macropore space and into the drain tile.

Effluent NO_3-N concentrations from sod covered tile drained Amity soil were < 1.0 ppm for plots receiving the waste slurry applications on 7 January through 29 April 1971 (Figure 15). The low effluent NO_3-N concentrations, < 1.0 ppm, were due to low winter soil temperatures which markedly reduce nitrification rates.

The initial total P concentrations in the drain tile effluents from the sod covered Amity sicl soil which received the high waste application rate ranged from 17.0 to 105.0 ppm (Table 17). The total P concentrations in the initial tile effluent from the sod covered plots which received the medium waste application rates were 14.0 to 78.0 ppm (Table 17). The maximum total P concentration in the initial drain tile effluent occurred three hours after the flow started from the drain tile. The initial total P content of the tile effluent was dependent upon the total P concentration of the applied waste slurry. The total P concentration in the tile effluent three weeks after application of the waste to the sod covered plots did not exceed 4.0 ppm and in most sample periods concentrations were < 1.0 ppm (Table 17).

The initial total P concentration of the drainage effluent from the desodded Amity sicl which received the high and medium rate of waste application were quite similar and ranged from 41.0 to 156.0 ppm (Table 18). The total P concentration in the drainage water from the control plots was as high as 33 ppm on 27 May 1971 (Table 18); but was generally less than 15 ppm.

The high total P concentrations in the effluent from the control plots indicated ground water bridging between waste treated plots and the control plots. This bridging occurred when the waste treated plot profile filled with liquid waste and the hydraulic head from the ponded waste forced the waste below the drain tile and the plastic film barrier. Lateral water movement allowed the waste to flow

Table 17. Phosphorus fixation by tile drained sod covered Amity soil receiving dairy wastes slurries.

Application date	Treatment rate (gal/plot)	Total P Applied (ppm)	Total P Effluent* (ppm)	Total P Fixed (%)	Total P** [3 weeks] (ppm)
1-7-71	0	0	2	--	< 1
	400	59	I. S.	--	< 1
	1000	59	I. S.	--	< 1
2-4-71	0	0	3	--	< 1
	400	73	14	85	2
	1000	73	17	81	< 1
3-4-71	0	0	2	--	1
	400	121	63	50	2
	1000	121	80	36	1
4-1-71	0	0	4	--	2
	400	100	62	38	4
	1000	100	82	18	4
4-29-71	0	0	I. S.	--	
	400	187	78	58	
	1000	187	105	44	
5-27-71	0	0		--	1
	400	90	39	56	
	1000	90	41	54	

*Maximum total P concentration in samples three hours after waste application.

**Average total P concentration in sample collected three weeks after waste application.

I. S. - insufficient sample.

Table 18. Phosphorus fixation by tile drained desodded Amity soil receiving dairy waste slurries.

Application date	Treatment rate (gal/plot)	Total P Applied (ppm)	Total P Effluent* (ppm)	Total P Fixed (%)	Total P** [3 weeks] (ppm)
1-21-71	0	0	14	--	< 1
	400	109	71	35	2
	1000	109	71	35	< 1
2-18-71	0	0	2	--	< 1
	400	79	41	49	< 1
	1000	79	47	40	1
3-16-71	0	0	10	--	< 1
	400	108	69	36	< 1
	1000	108	66	39	3
4-15-71	0	0	4	--	11
	400	270	134	50	16
	1000	270	156	42	5
5-27-71	0	0	33	--	< 1
	400	87	43	51	7
	1000	87	53	40	1

*Maximum effluent concentration following waste application.

**Average total P concentrations in samples collected three weeks after the waste application.

from the treated plots into the control plot drain tile.

The high total P concentrations in the tile drainage waters resulted primarily from the tile backfill compaction problems that have been discussed earlier.

Ground Water From Undrained Plots

The NH_4-N concentration of the ground water sampled thirty minutes after the high application rate of waste was added to the sod covered plots ranged from 4.0 to 30.0 ppm (Table 19). The NH_4-N concentration in water samples collected from the same plots three weeks after the application date ranged between 3.0 and 13.0 ppm (Table 19). The initial groundwater NH_4-N content in the sodded plots which received the medium waste application rates ranged from 2.0 to 12.0 ppm. After three weeks the NH_4-N level had decreased to less than 7.0 ppm.

The initial groundwater NH_4-N concentrations from desodded Amity soil receiving the medium and high waste applications throughout the winter did not exceed 15.0 ppm (Table 20). The NH_4-N concentration of the groundwaters three weeks after application did not exceed 7.0 ppm (Table 20) and after were < 1.0 ppm.

The groundwater NH_4-N concentrations from the control plots did notexceed 1.0 ppm throughout the winter application period.

Table 19. NH_4-N concentration in groundwaters from sod covered Amity sicl soil receiving dairy waste slurries.

Application date	Treatment rate (gal/plot)	NH_4-N Applied (ppm)	Groundwater* (ppm)	Removed (%)	NH_4-N** [3 weeks] (ppm)
1-7-71	0	0	2	--	0
	400	103	12	73	5
	1000	103	30	90	13
2-4-71	0	0	0	--	0
	400	63	2	97	1
	1000	63	7	90	3
3-4-71	0	0	0	--	0
	400	104	1	99	1
	1000	104	4	96	3
4-1-71	0	0	0	--	0
	400	63	4	94	1
	1000	63	15	77	5
4-29-71	0	0	0	--	1
	400	78	11	86	7
	1000	78	16	76	7
5-27-71	0	0	1	--	1
	400	28	9	70	6
	1000	28	15	49	11

*NH_4-N concentrations in samples collected one day after waste application.

**NH_4-N concentration in samples collected three weeks after waste application.

Table 20. NH_4-N concentration in groundwaters from desodded Amity sicl soil receiving dairy waste slurries.

Application date	Treatment rate (gal/plot)	NH_4-N Applied (ppm)	Groundwater* (ppm)	Removed (%)	NH_4-N** [3 weeks] (ppm)
1-21-71	0	0	0	--	0
	400	101	1	99	0
	1000	101	1	99	0
2-18-71	0	0	0	--	0
	400	103	1	99	0
	1000	103	3	97	1
3-16-71	0	0	0	--	0
	400	95	2	98	0
	1000	95	7	93	2
4-15-71	0	0	1	--	0
	400	90	9	90	6
	1000	90	15	84	6
5-27-71	0	0	0	--	0
	400	29	12	57	9
	1000	29	9	69	0

*NH_4-N concentrations in samples collected one day after waste treatment

**NH_4-N concentration in samples collected three weeks after waste treatment.

Groundwater NO_3-N concentrations from the sod covered Amity soil remained < 1.0 ppm throughout the winter application period (Figure 25).

The maximum total P concentration in the groundwater after the high rate of waste application to the sod covered Amity sicl ranged from 4.0 to 62.0 ppm (Table 21). The total P concentration in the groundwater three weeks after the application of the waste slurries decreased to a range from 2.5 to 35.0 ppm. Groundwater total P concentrations from the control plots remained < 3.0 ppm throughout the Winter 1971 application period (Table 21).

The total P content of the groundwater from the desodded plots which received the high and medium waste application rates ranged from 4.0 to 54 ppm. The total P content of the groundwater was less than 10.0 ppm for January, February and March but increased to 30 and 50 ppm total P during April and May. The total P concentrations in the groundwater from the desodded plots three weeks after the application of medium and high waste rates were < 4.0 ppm, except for 27 May application date when total P concentrations were 39.0 and 32.0 ppm, respectively (Table 22). Groundwater was probably contaminated due to the selective flow channels around the well casings in late spring. The total P content of the groundwater for the control treatment did not exceed 4.0 ppm during the Winter 1971 application period.

Table 21. Total P concentration in groundwaters from sod covered Amity soil receiving dairy waste slurries.

Application date	Treatment rate (gal/plot)	Total P Applied (ppm)	Total P Groundwater* (ppm)	Total P Fixed (%)	Total P** [3 weeks] (ppm)
1-7-71	0	0	< 1	--	< 1
	400	59	I. S.	--	16
	1000	59	I. S.	--	20
2-4-71	0	0	2	--	< 1
	400	73	4	97	3
	1000	73	5	96	4
3-4-71	0	0	1	--	2
	400	121	7	96	2
	1000	121	7	96	5
4-1-71	0	0	2	--	3
	400	100	12	90	6
	1000	100	23	79	20
4-29-71	0	0		--	
	400	187	46	77	15
	1000	187	55	72	
5-27-71	0	0	3	--	
	400	90	42	34	33
	1000	90	62	56	35

*Maximum total P concentrations in samples collected one to two days after waste application.

**Total P concentrations in samples collected three weeks after waste application.

I. S. - Insufficient sample.

Table 22. Total-P concentration in groundwaters from desodded Amity soil receiving dairy waste slurries.

Application date	Treatment rate (gal/plot)	Total P Applied (ppm)	Total P Groundwater* (ppm)	Total P Fixed (%)	Total P** [3 weeks] (ppm)
1-21-71	0	0	< 1	--	< 1
	400	109	4	96	2
	1000	109	4	96	2
2-18-71	0	0	1	--	< 1
	400	79	4	94	1
	1000	79	6	92	2
3-16-71	0	0	2	--	1
	400	108	10	91	1
	1000	108	14	87	4
4-15-71	0	0	4	--	2
	400	270	33	88	3
	1000	270	33	88	3
5-27-71	0	0	4	--	4
	400	87	54	38	39
	1000	87	35	59	32

*Maximum total P concentrations in sample collected one to two days after waste applications.

**Total P concentrations in samples collected three weeks after waste application.

Ammonium Nitrogen and Total Phosphorus Removal By Drained and Undrained Amity sicl Soil

The NH_4-N and total P removed from the applied dairy waste slurries were calculated from the concentration differences between the applied waste and the drain tile effluent and groundwater. The total P and NH_4-N removal was determined from the maximum effluent concentrations in the tile drains within three hours after application and maximum groundwater concentrations one day after waste application. Therefore, the minimum removal would be calculated to ascertain the effectiveness of the soil as a filter.

Ammonium Nitrogen

The NH_4-N removal from the waste applied at the medium rate to the sod covered tile drained plots was only 33% (Figure 11) for the first application date, 7 January. The principal cause for the low percentage of NH_4-N removal was related to the tile backfill problems. The NH_4-N removal from the wastes applied from February through May increased to approximately 80%. The selective water movement through the tile backfill appeared to be reduced but was still considered a major problem, as evidenced by very rapid tile drain flow rates.

Approximately 80% of the NH_4-N applied in the dairy waste was adsorbed by the soil in the desodded tile drained plots.

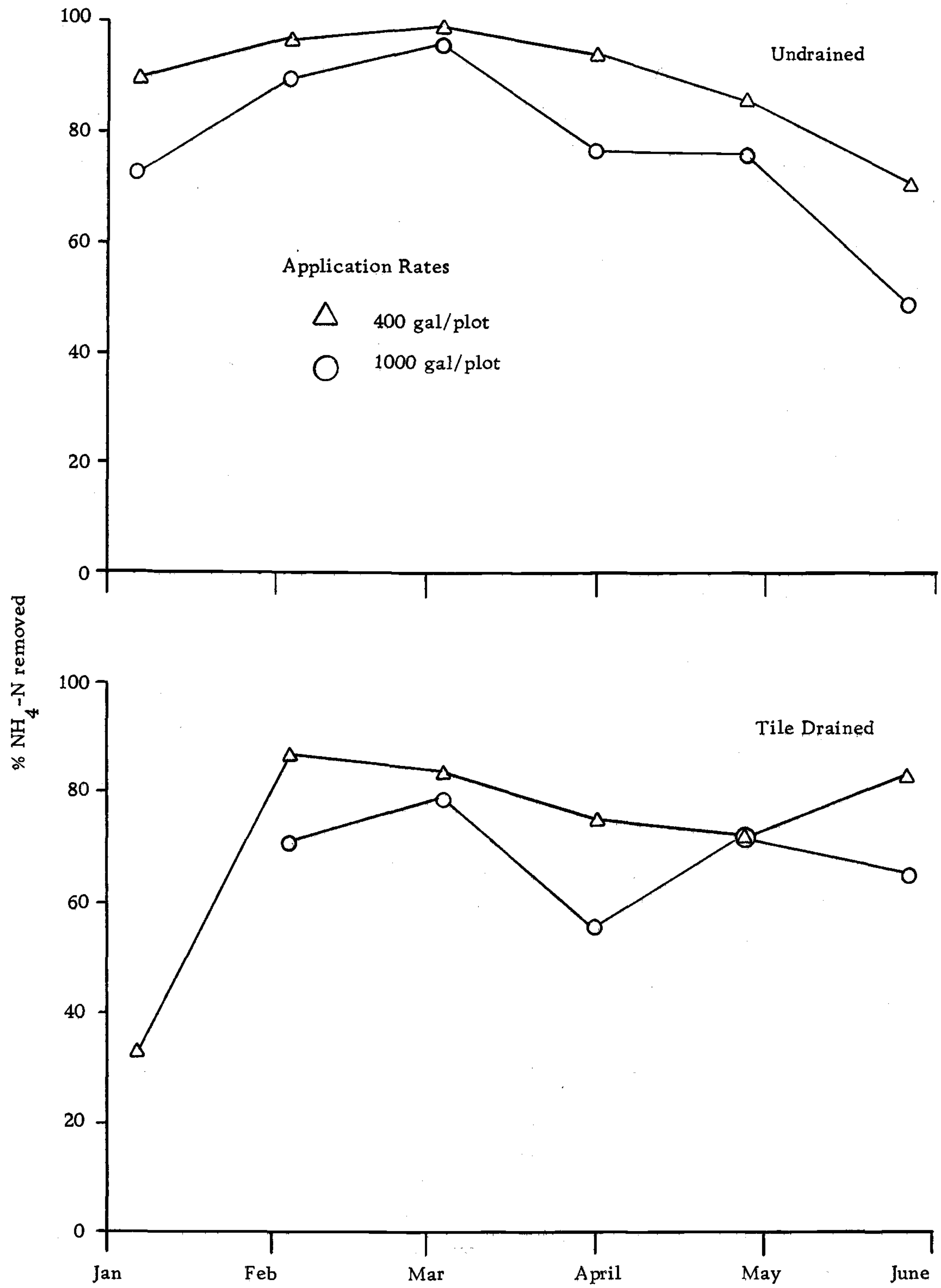


Figure 11. NH_4-N removed by sod covered Amity soil receiving dairy waste slurries.

Consistently 10 to 15% more NH_4-N was removed by the soil when the waste was applied at the lower rate. The NH_4-N removal, when the high waste application was made, increased steadily from 55 to 76% for the application periods from 21 January through 27 May 1971 (Figure 12).

The removal of NH_4-N from the dairy waste slurries applied at the medium and high rates to the undrained sod covered and desodded Amity soil was 75 to 99% from 7 January to 1 April 1971. After the April application the NH_4-N removal decreased to 60 to 70% (Figure 11 and 12).

Total Phosphorus

The total P fixed by the tile drained sod covered Amity sicl soil plots receiving high waste applications decreased from 81% on 4 February to a fairly stable level around 40 to 50% (Figure 13). The total P fixed by the sod covered plots receiving medium waste applications was not significantly different from plots which received the high waste application. The total P fixation by the tile drained desodded Amity sicl soil which received the medium and high waste application, remained at 40% throughout the winter months (Figure 14).

The total P fixed by the undrained desodded and sod covered Amity sicl plots receiving the medium and high waste applications

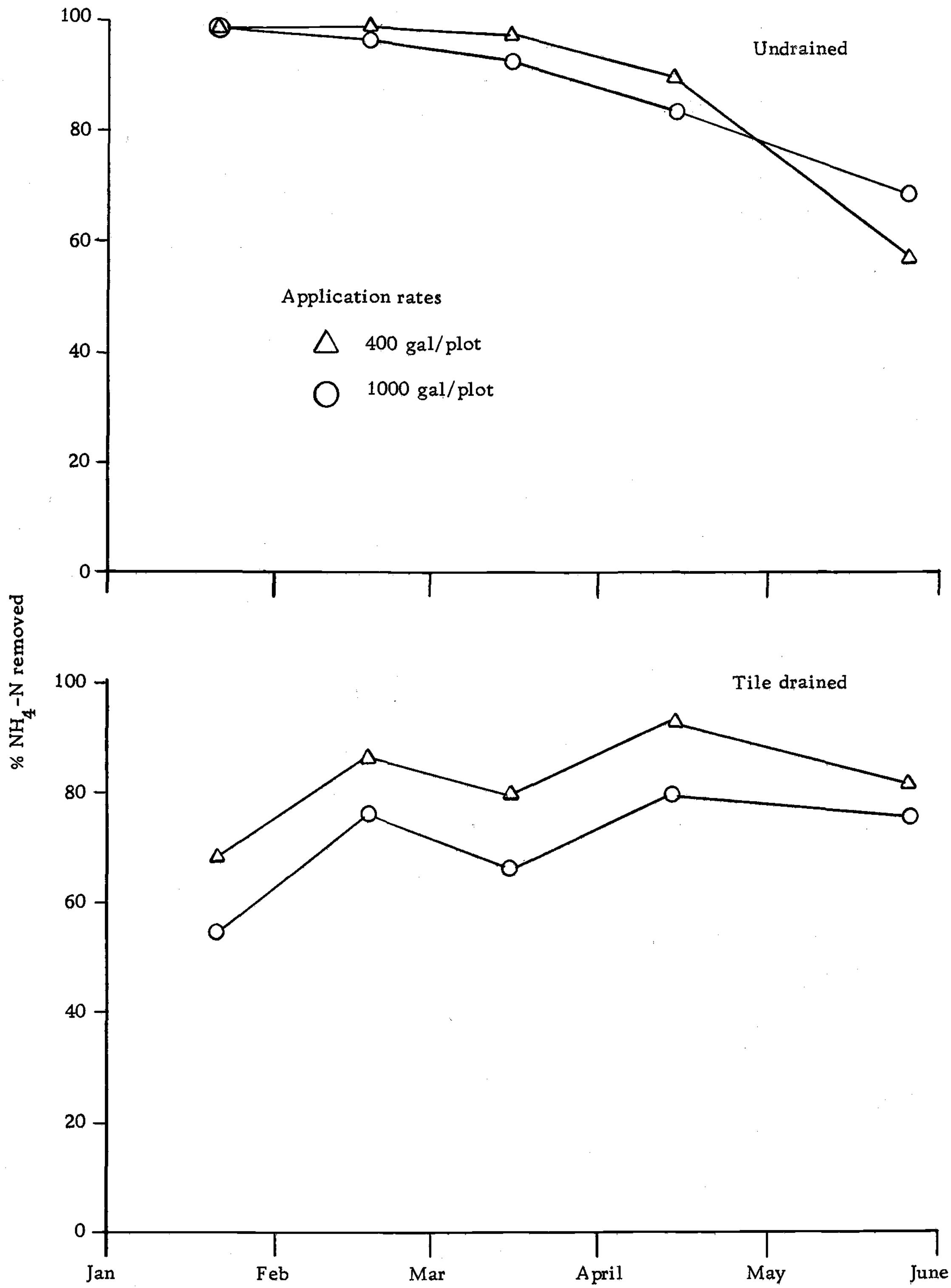


Figure 12. NH_4-N removed by desodded Amity soil receiving dairy waste slurries.

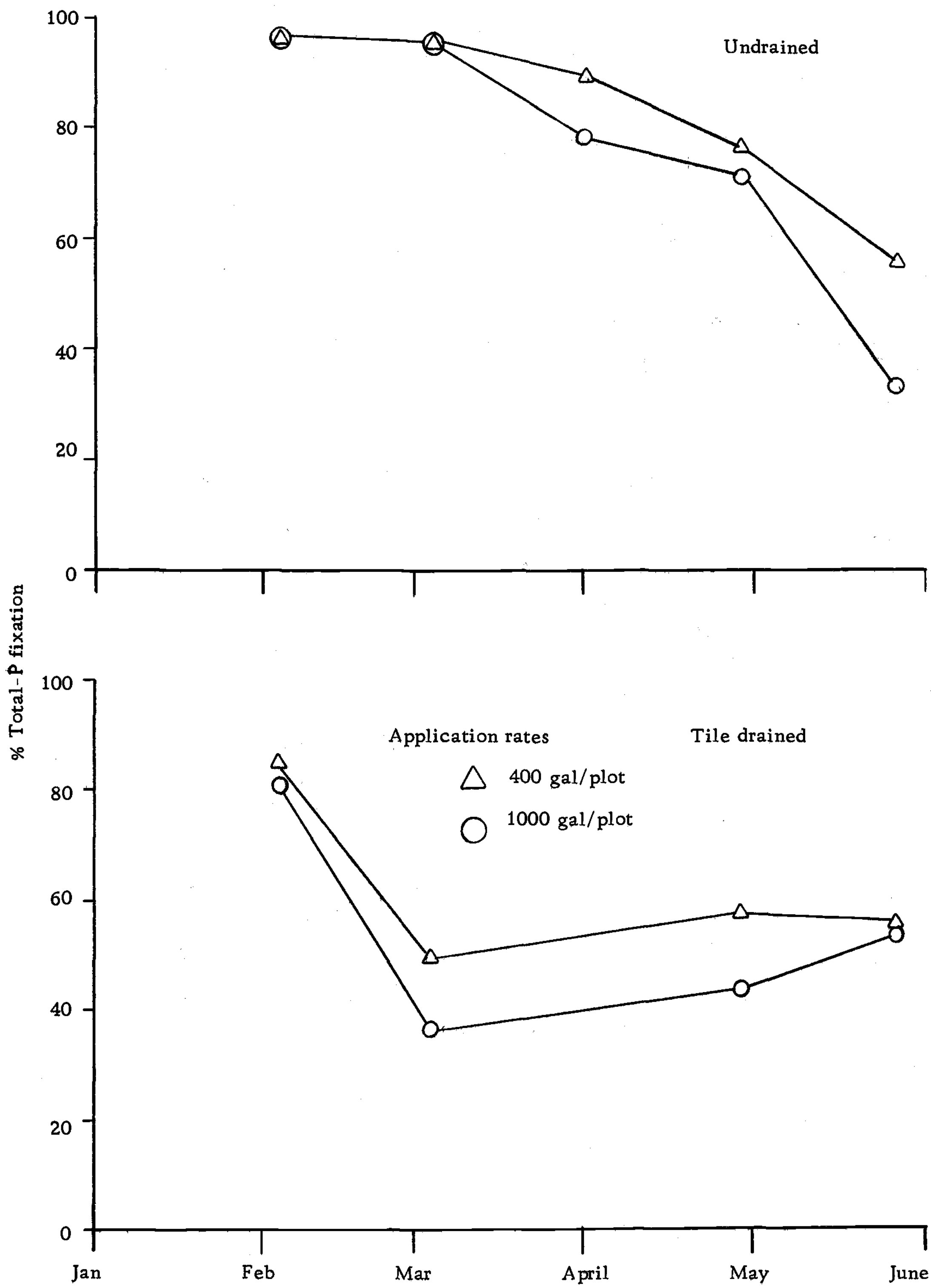


Figure 13. Total P fixation by sod covered Amity soil receiving dairy waste slurries.

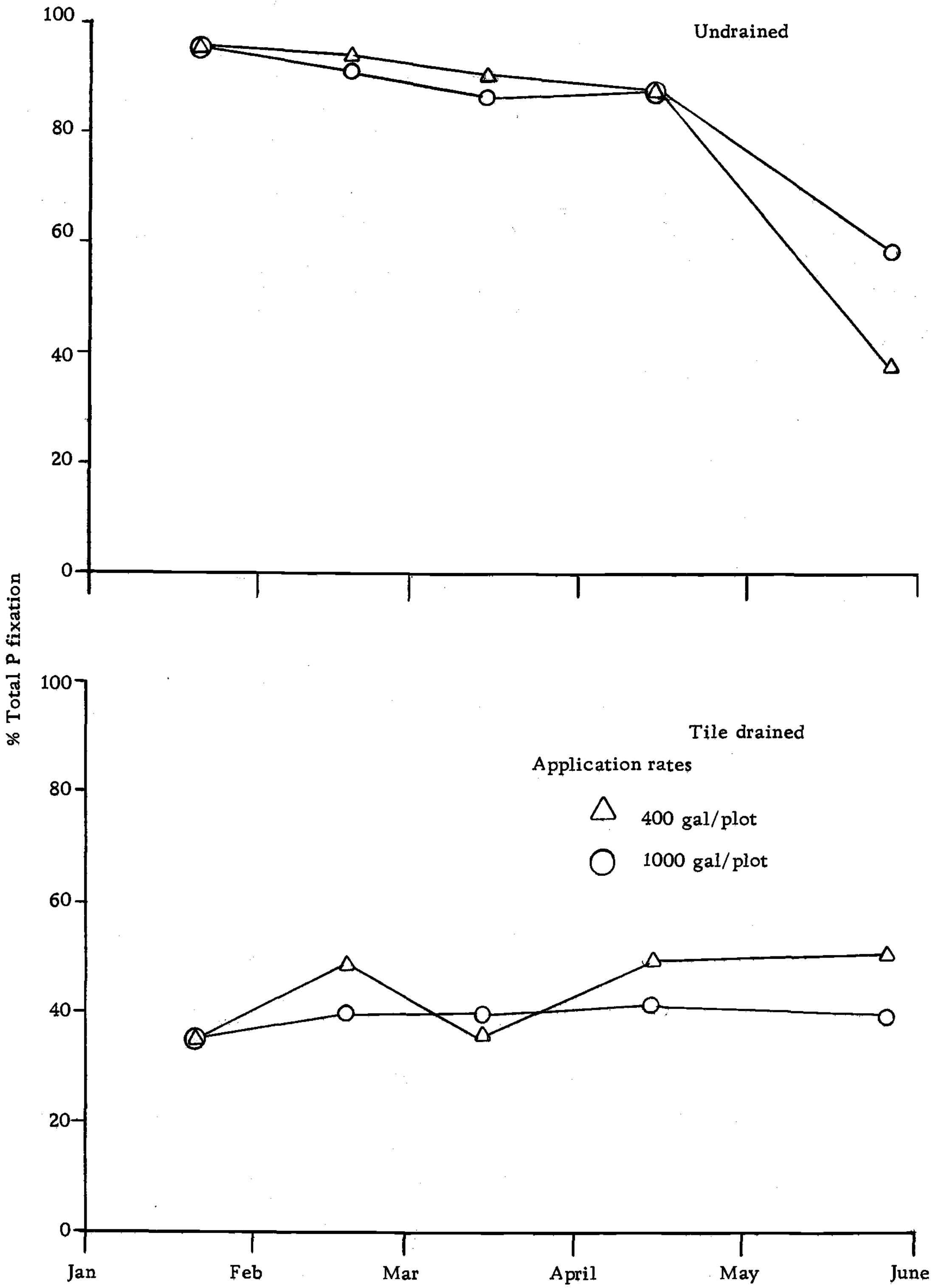


Figure 14. Total P fixation by desodded Amity soil receiving dairy waste slurries.

were essentially the same (Figures 13 and 14). The total P fixed by the Amity sicl soil decreased from approximately 90% after the first application of liquid waste to 40 and 60% on 27 May 1971.

Animal Waste Applications During Summer 1971

Prior to the summer waste application the tile backfill was excavated. Layers of soil and bentonite clay were retamped in the tile trench. The backfill tamping operation was designed to remove water channels and reduce tile effluent flow rates.

Applied Dry Matter, Nitrogen and Phosphorus

After the four summer waste applications to the sod covered plots, the dry matter accumulation totaled 20.5 and 47.5 tons per acre for the medium and high waste applications respectively (Table 23). The cumulative dry matter for desodded plots receiving medium and high waste applications were 21.5 and 50.5 tons per acre, respectively (Table 23).

Dry matter accumulations on the Amity sicl soil plots which received medium and high waste applications averaged 1.5 and 4.0 inches respectively. The thatch of waste dry matter on the sodded lots which received the high waste application prevented emergence of the sod grass.

The quantity of total -N applied to the sod covered plots which

Table 23. Summer application of dairy waste solids, nitrogen and phosphorus to Amity SiCl soil.

Application date	Nitrogen applied						Phosphorus applied		Total solids applied	
	Total-N		NH_4-N		NO_3-N		Total-P			
	lbs/acre									
Sod	A*	B	A	B	A	B	A	B	A	B
7-16-71	205	512	120	300	1.5	4.6	208	520	6950	16250
8-5-71	184	461	100	245	0.8	1.9	215	587	13800	32300
8-19-71	146	366	104	260	0.2	0.6	84	211	4780	11300
9-2-71	240	600	100	250	0.8	1.0	128	320	15100	25000
Total	775	1939	424	1055	2.8	8.1	635	1588	40630	94850
Desodded										
7-16-71	281	707	130	324	1.2	3.0	295	740	30300	70800
8-5-71	166	417	100	248	0.8	1.9	123	308	3260	7600
8-19-71	256	377	105	263	0.2	0.4	72	181	2500	6000
9-2-71	930	577	94	235	0.5	1.2	97	242	7300	16400
Total	933	2078	429	1070	2.7	6.5	587	1471	43420	100800

*A = 400 gal/plot application rate.
B = 1000 gal/plot application rate.

received the medium and high waste applications totaled 775 and 1939 pounds per acre, respectively for the four summer applications. The total -N applied to the desodded plots with medium and high waste application rates equaled 933 and 2078 pounds per acre, respectively (Table 23).

The NH_4-N applied to the plots was approximately 50% of the total -N applied, with very small quantities of NO_3-N applied (Table 23).

Both the desodded and the sodded plots received approximately 600 and 1600 pounds per acre of total P from the medium and high waste applications respectively (Table 23).

Drain Tile Effluent

Effluent Flow Rates

Peak effluent flow rates after application of the dairy wastes during the summer still exceeded the weir system, even after the soil repacking operation. Effluent flow rates from plots receiving the waste application exceeded 1200 ml per minute, while the capacity was 800 ml per minute. The high effluent flow rates resulted from the high hydraulic conductivity, hydraulic heads, and some soil cracking in the plot area.

Nitrogen and Phosphorus Constituents

The NH_4-N concentration of the waste slurry applied in the summer months was twice the NH_4-N concentration of the slurry applied in the winter. Average initial effluent NH_4-N concentrations, one to two hours after the medium and high rates of waste application, ranged from 30 to 92 ppm for the summer application period 16 July through 2 September 1971 (Table 24). The effluent NH_4-N concentrations in the drainage water from the control treatment were < 1.0 ppm throughout the summer.

Tile effluent NH_4-N concentrations in the drainage water from the desodded Amity sicl soil receiving the medium and high waste applications were 60 to 80 ppm throughout the application period. No tile effluent samples after the day of waste application were collected due to the lack of rainfall (Table 24).

The NO_3-N concentration in the tile effluent from the plots which received the high waste application rate were 7.8 ppm for 16 July and always remained above 5.0 ppm. The NO_3-N concentrations in the effluent from the plots which received the medium waste applications increased after 27 May from < 1.0 ppm to 5.8 ppm on 19 August 1971. The NO_3-N concentrations of effluent water from plots receiving no waste increased from < 1.0 ppm to 8.0 ppm for the period 27 May through 2 September 1971 (Figure 15). The NO_3-N

Table 24. NH_4-N concentrations in tile effluent from sod covered and desodded Amity soil receiving dairy waste slurries.

Application date	Application rate (gal/plot)	NH_4-N Applied (ppm)	NH_4-N Initial* (ppm)	NH_4-N Removed (%)
		Sod covered		
7-16-71	0	0	0	-
	400	249	84	66
	1000	249	66	74
8-5-71	0	0	0	-
	400	204	31	85
	1000	204	63	69
8-19-71	0	0	0	-
	400	215	83	61
	1000	215	92	57
9-2-71	0	0	0	-
	400	208	37	82
	1000	208	48	77
		Desodded		
7-16-71	0	0	1	-
	400	268	I. S.	-
	1000	268	80	70
8-15-71	0	0	1	-
	400	204	62	70
	1000	204	86	58
8-19-71	0	0	1	-
	400	217	78	64
	1000	217	119	45
9-2-71	0	0	0	-
	400	194	16	92
	1000	194	81	58

*NH_4-N concentrations in samples collected one to two hours after waste application.

I. S. - Insufficient sample

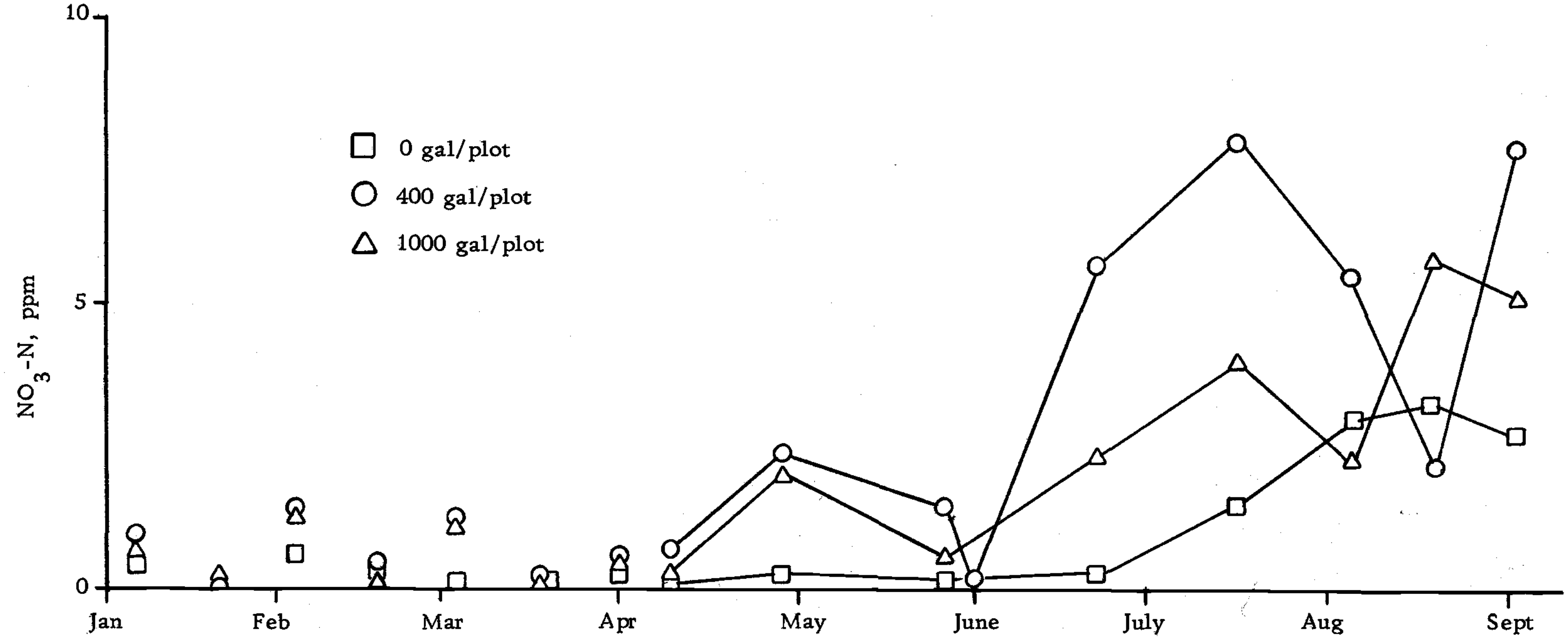


Figure 15. NO_3-N concentrations of tile effluent from sod covered Amity soil receiving applications of dairy waste slurries.

concentration measured in the tile effluent water reflected the increased nitrification with increase in soil temperature.

The total P concentration in the effluent from the plots receiving the medium waste applications generally decreased during the application period (Table 25). The total P fixed varied from 24 to 83% for the application period 16 July through 2 September 1971, (Table 25) when applied to sod and desodded drained Amity soil in tile drained plots.

It was difficult to assess the true effect that repacking the backfill trenches had on tile drain effluent. During the summer months the soil cracked badly having large channels for preferential water flow.

Groundwater From Undrained Plots

The groundwater NH_4-N concentration in the sodded plots with no drainage, but which received waste, ranged from 118 to 133 ppm (Table 26) for the first waste application. The groundwater NH_4-N concentration decreased steadily down to 5.0 to 11.0 ppm after the last waste application. Prior to the final waste application the soil surface had cracked and allowed groundwater contamination from waste percolation beside the tube wall. Though the tubes were purged dry prior to sample collection some waste water could have

Table 25. Tile drain effluent total P concentrations from sod covered and desodded Amity sicl soil receiving dairy waste slurries.

Application date	Application rate (gal/plot)	Total P Applied (ppm)	Total P Initial* (ppm)	Total P Fixed (%)
		Sod covered		
7-16-71	0	0	4	-
	400	430	255	41
	1000	430	261	39
8-5-71	0	0	4	-
	400	445	78	83
	1000	445	106	76
8-19-71	0	0	2	-
	400	175	135	24
	1000	175	106	41
9-2-71	0	0	1	-
	400	265	97	64
	1000	265	110	58
		Desodded		
7-16-71	0	0	4	-
	400	610	I. S.	I. S.
	1000	610	447	27
8-5-71	0	0	2	-
	400	225	93	59
	1000	225	160	29
8-19-71	0	0	2	-
	400	150	I. S.	I. S.
	1000	150	132	12
9-2-71	0	0	2	-
	400	200	96	52
	1000	200	139	31

*Effluent total P concentration in samples collected one to two hours after waste applications.

I. S. - Insufficient sample

Table 26. Groundwater NH_4-N concentration in desodded and sod covered Amity soil receiving dairy wastes slurries.

Application date	Application rate (gal/plot)	NH_4-N Applied (ppm)	Initial* (ppm)	Removed (%)	Final** [1 week] (ppm)
		Sod Covered			
7-16-71	0	0	0	--	
	400	249	118	53	1
	1000	249	133	47	2
8-5-71	0	0	0	--	
	400	204	37	82	6
	1000	204	19	90	22
8-19-71	0	0	0	--	
	400	215	31	86	22
	1000	215	28	87	20
9-2-71	0	0	1	--	0
	400	208	5	98	5
	1000	208	11	95	6
		Desodded			
7-16-71	0	0	0	--	1
	400	268	14	95	2
	1000	268	56	79	7
8-5-71	0	0	0	--	0
	400	204	9	95	7
	1000	204	15	93	9
8-19-71	0	0	0	--	0
	400	217	15	93	10
	1000	217	10	96	7
9-2-71	0	0	0	--	0
	400	194	6	97	4
	1000	194	13	94	6

*Groundwater NH_4-N concentration in samples collected one to two days after waste application.

**Groundwater NH_4-N concentration in samples collected one week after waste application.

reentered the sample tubes. After the 16 July waste application the soil swelled and sealed the sample wells.

The groundwater NH_4-N concentration one day after waste applications to the undrained desodded plots was < 15 ppm through the summer. The groundwater NH_4-N concentrations one week after waste applications for both application rates of waste slurries (Table 26) decreased significantly. The groundwater NH_4-N concentrations in the check plots did not exceed 1 ppm.

The groundwater NO_3-N concentration in the sodded plots receiving the medium waste application increased from 1.0 to 5.9 ppm on 16 July. After the 2 September waste application, the NO_3-N concentration in the groundwater from the sodded plots which received the medium and high waste applications were 8.4 ppm and 0.7 ppm, respectively (Figure 16). The reduced NO_3-N concentration in the water on the plots which received the high waste application may have resulted from denitrification induced by water logged conditions. The groundwater NO_3-N concentration in the control plots was < 1.0 ppm throughout the summer application period (Figure 16).

The total P concentration in the groundwater one day after the application of the waste to the sod covered Amity sicl was 200 to 310 ppm for the 16 July application date (Table 27). These total P concentrations were high with respect to P levels in water sampled between 5 August and 2 September 1971 for both the sod covered and

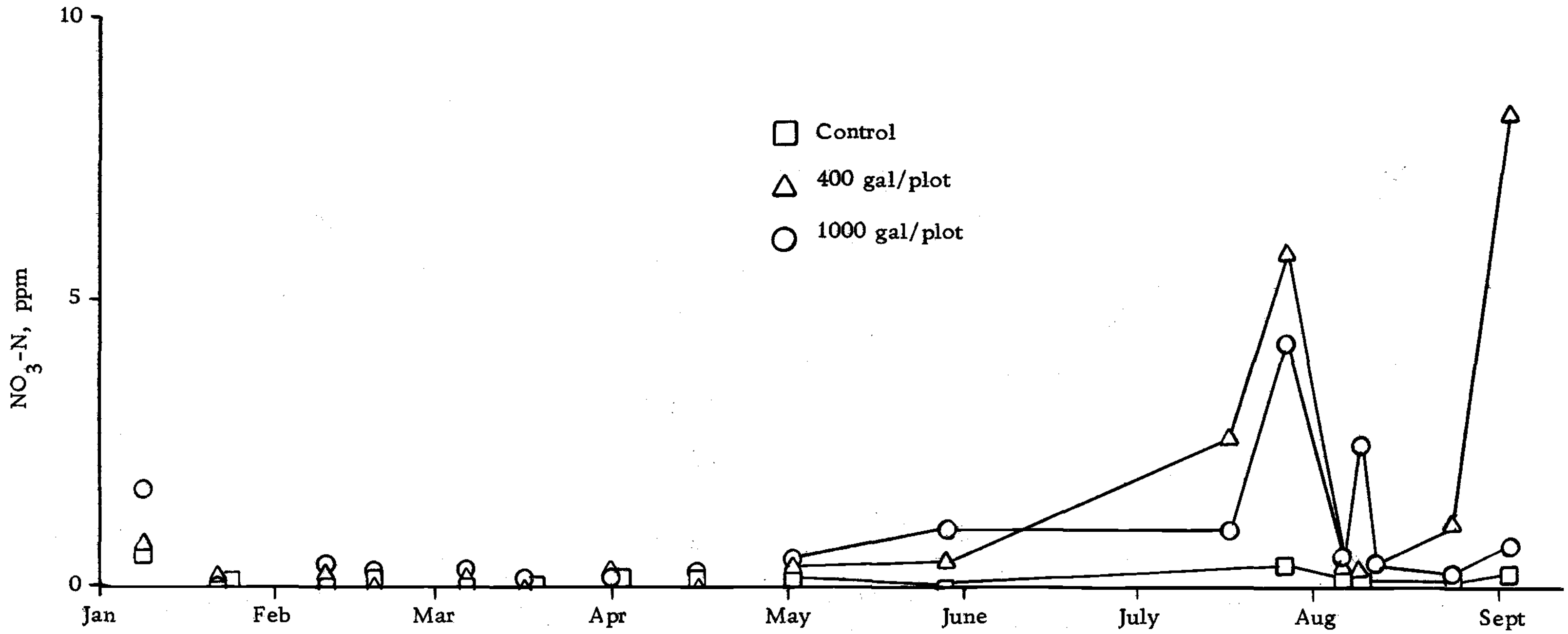


Figure 16. Groundwater NO_3-N concentrations from sod covered Amity soil.

Table 27. Groundwater total-P concentrations from sod covered and desodded Amity sicl soil receiving dairy waste slurries.

Application date	Application rate (gal/plot)	Total P Applied (ppm)	Initial* (ppm)	Removed (%)	Final** [1 week] (ppm)
		Sod Covered			
7-16-71	0	0	5	--	
	400	430	230	52	6
	1000	430	310	28	15
8-5-71	0	0	5	--	
	400	445	60	87	41
	1000	445	69	84	54
8-19-71	0	0	1	--	< 1
	400	175	41	77	29
	1000	175	100	43	45
9-2-71	0	0	5	--	1
	400	265	31	88	15
	1000	265	58	78	39
		Desodded			
7-16-71	0	0	21	--	13
	400	610	70	88	19
	1000	610	192	69	26
8-5-71	0	0	5	--	2
	400	255	40	84	31
	1000	255	60	76	45
8-19-71	0	0	3	--	2
	400	150	26	83	22
	1000	150	26	83	3
9-2-71	0	0	4	--	2
	400	200	12	94	9
	1000	200	39	81	25

*Groundwater total P concentration in samples collected one to two days after waste application.

**Groundwater total P concentration in samples collected one week after waste application.

desodded plots (Table 27). At the later dates the P concentration ranged from 30 to 60 ppm. These results would indicate less soil cracking and shrinking around the sample well case. The groundwater total P concentrations from control plots were < 5.0 ppm, except for 16 July (Table 27).

Ammonium Nitrogen and Total Phosphorus Removal

The NH_4-N and total -P removed from the applied dairy waste were calculated from the concentration differences between the applied waste and the drain tile effluent and groundwater. The total -P and NH_4-N removal was determined from the maximum effluent concentrations in the tile drains within three hours after waste slurry application and maximum groundwater concentrations one day after waste applications. Therefore, the minimum removal would be calculated to ascertain the effectiveness of the soil as a filter.

Ammonium Nitrogen

Approximately 70-80% of the NH_4-N was removed by the Amity sicl soil in the sod covered and tiled plots (Figure 17). The average NH_4-N removal by the soil in the desodded plots with tile drainage was from 60 to 75% (Figure 18). The NH_4-N removed from the liquid dairy wastes applied to the sod covered plots with no tile drainage increased from 50% on 16 July to 95% on 2 September 1971

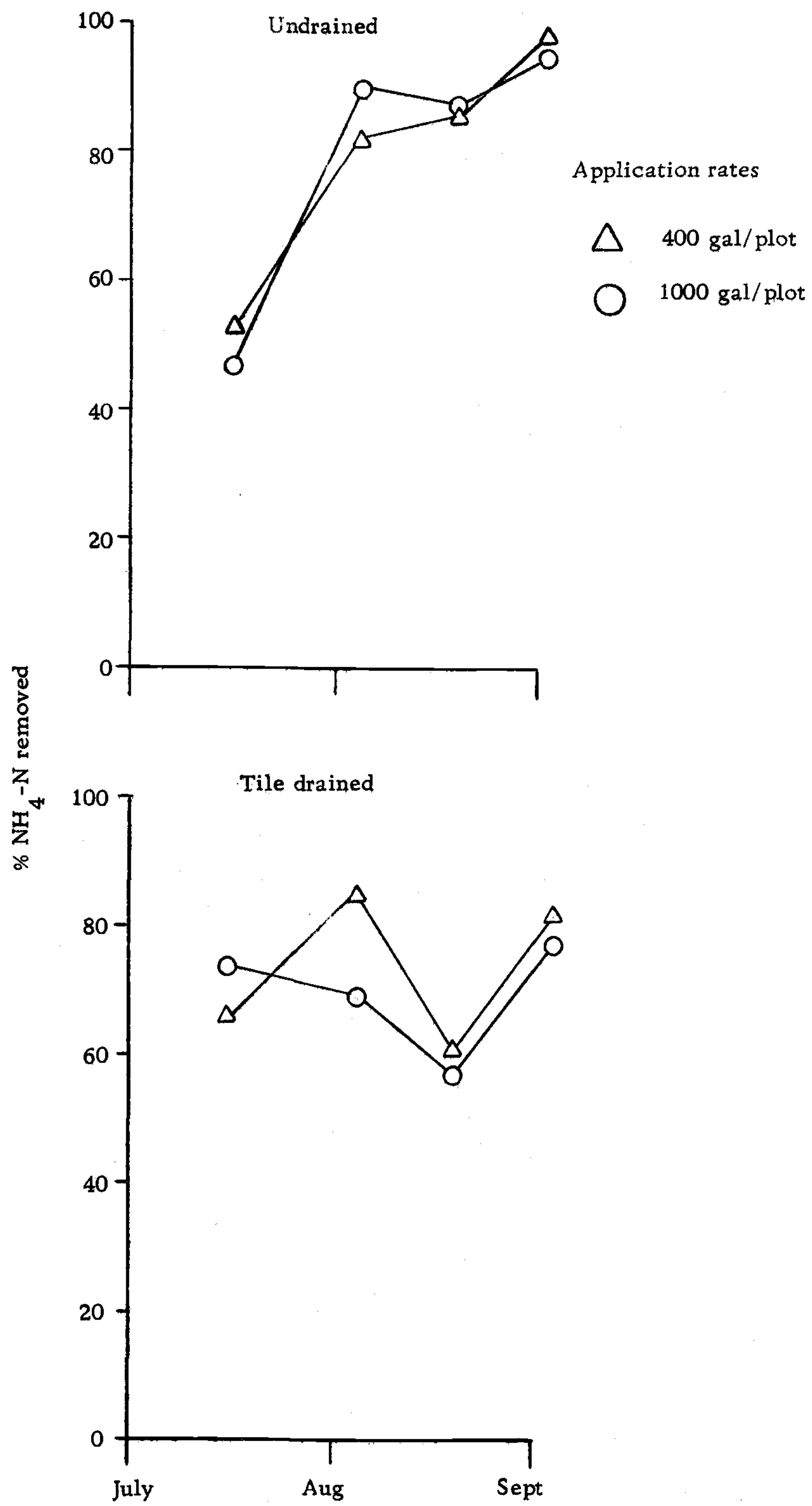


Figure 17. NH_4-N removed by sod covered Amity soil receiving dairy waste slurries.

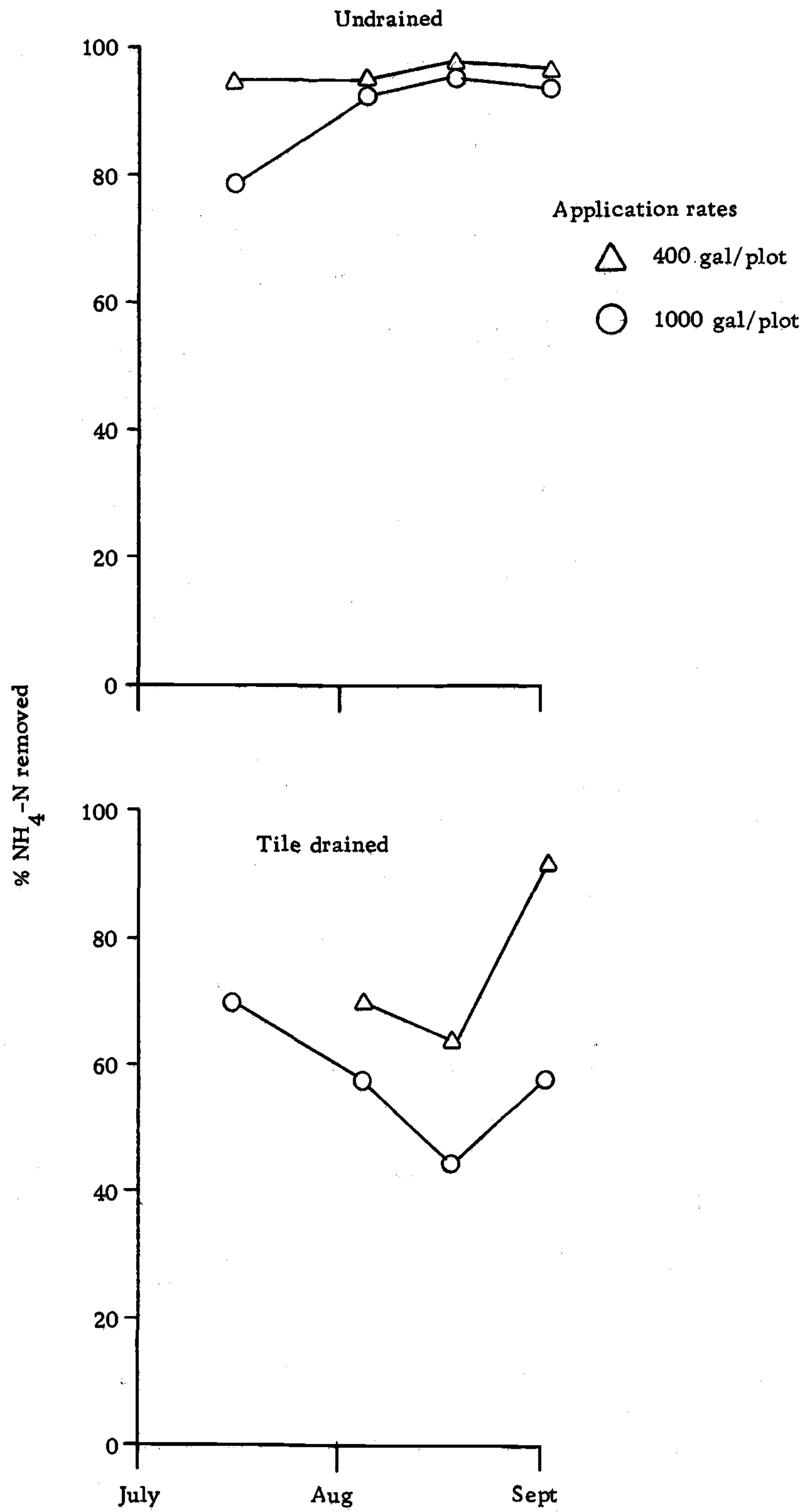


Figure 18. NH_4-N removed by desodded Amity soil receiving dairy waste slurries.

(Figure 17). The NH_4-N removal by undrained Amity soil in the desodded plots which received the high and medium application rates of waste slurries was 80% to 95% through the summer application period (Figure 18).

Undrained Amity soil removed 15 to 20% more NH_4-N from the applied liquid dairy waste than the tile drained Amity sicl soil. More NH_4-N was removed by the soil in the undrained plots because of extended contact time between the soil and the waste product.

Total Phosphorus

The total P fixed by the Amity sicl which was sod covered, averaged 50% (Figure 19). The phosphorus fixed varied considerably for the 16 July through 2 September 1971 application period. The total P fixed was equivalent to 340 and 840 pounds per acre for the medium and high application rate of dairy waste, respectively. The varied total P fixation was possibly caused by the surface soil drying and cracking to allow rapid movement of liquid wastes to the drain tile lines.

The percentage of total P fixation by the desodded Amity sicl soil with tile drainage and receiving high waste applications was 12 to 30%. Total P fixation for medium application rates of waste slurries was 50 to 60% (Figure 20). Groundwater contamination by movement of waste liquids into the sample wells caused the low P

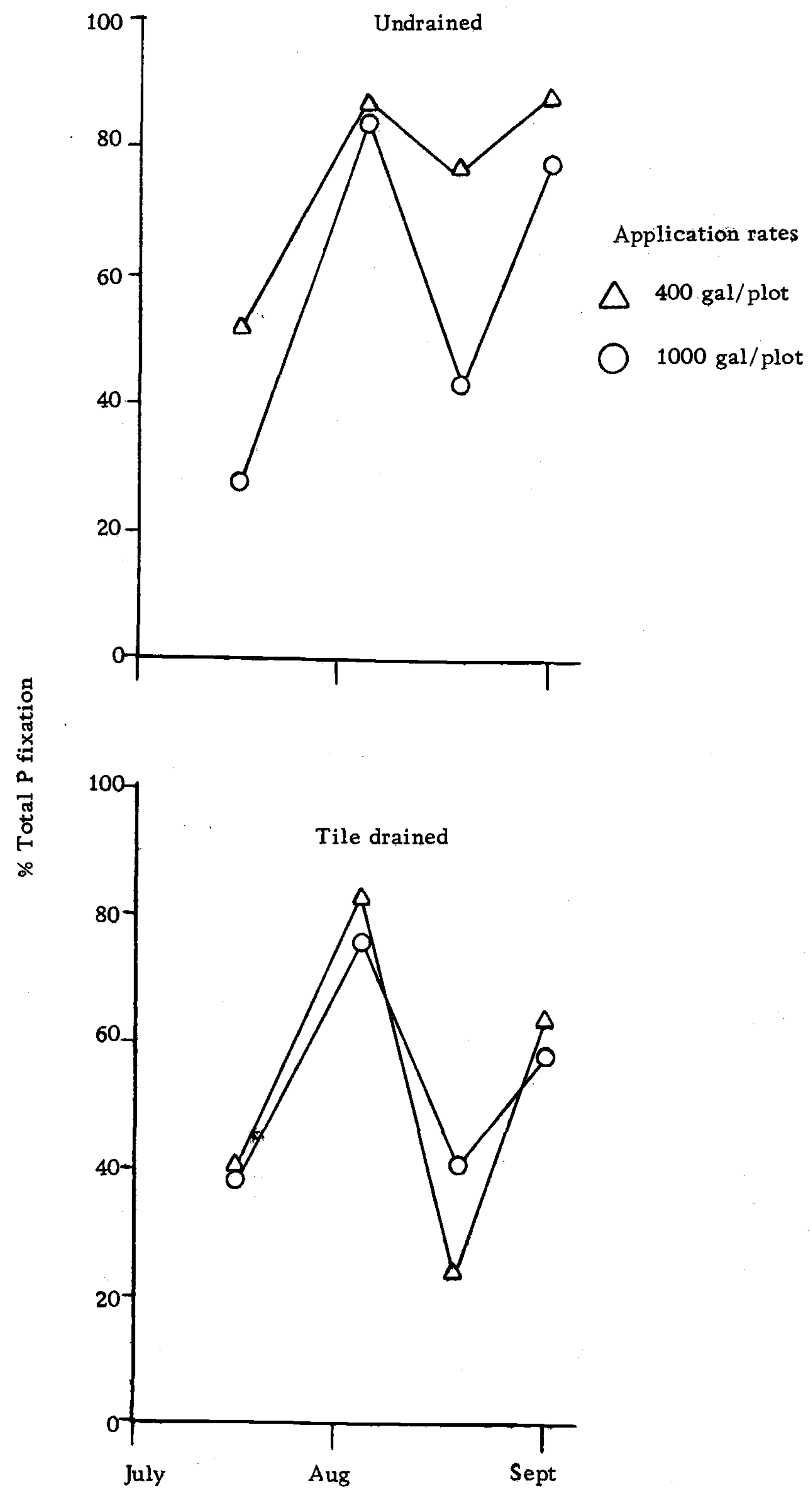


Figure 19. Total P fixation by sod covered Amity sicl soil receiving dairy waste slurries.

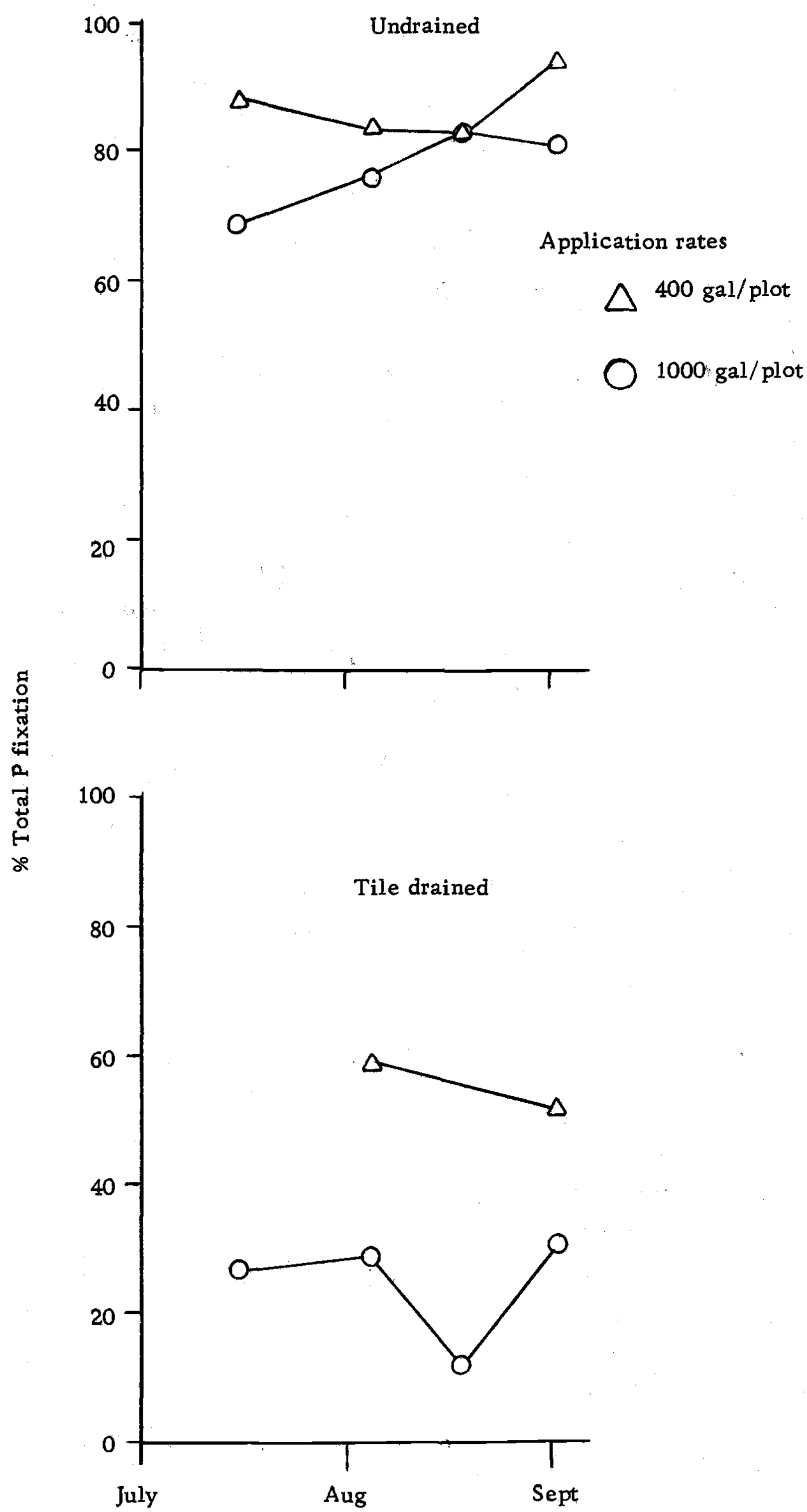


Figure 20. Total P fixation by desodded Amity sicl soil receiving dairy waste slurries.

fixation for the high waste application. The total P concentrations at a three foot depth should be < 1.0 ppm (63). If the soil has saturated the phosphorus fixing capacity of the groundwater would contain high P concentrations, but this is unlikely since the Amity sicl soil contains 30 to 35% clay.

Phosphorus fixation by the undrained desodded plots of Amity sicl soil exceeded the tile drained soil phosphorus fixation by 30 to 40%. Total P fixation by the Amity soil which received the high waste application rate was 70 to 85% (Figure 20).

Waste Application Frequency Determined By Soil Moisture Criteria

A study was initiated to determine if increased liquid waste-soil contact time would maximize the removal of nitrogen and phosphorus. To increase the soil-waste contact time, waste applications were halted if the soil moisture content exceeded field capacity, approximately 0.1 bar tension. A control plot and a similar total application rate were included in the study using no soil moisture criteria. The waste treatments were applied to drained and undrained desodded plots.

Drain Tile Effluent

Nitrogen fractions, total -N, NH_4-N and total P, were analyzed in the tile effluent water. Two samples were collected after the application of the waste. The initial sample was collected 20 to 40 minutes after the waste application and a final sample approximately two hours after waste application.

The total-N concentration in the applied liquid wastes ranged from 315 to 470 ppm over the application period (Table 28). In the initial sample the total-N concentration of the tile drain effluent from plots receiving one acre-inch of waste slurry each day ranged from 47 to 122 ppm over the application period. The total-N concentration in the final tile effluent from plots which received one inch of liquid waste, increased 2.0 to 40.0 ppm more than the initial sample. The effluent total N concentration from the control plots which received two acre-inches of irrigation water every two days was 6.0 ppm (Table 28).

In the initial sample the NH_4-N concentration after one acre-inch of liquid waste was applied ranged from 6 to 26 ppm. The effluent NH_4-N concentration in the final sample increased, and ranged from 16 to 32 ppm (Table 29). The tile effluent flow continued for three to four hours, but as surface sealing occurred with later applications lower flow rates occurred and flow periods were extended six to seven hours. The NH_4-N removed from one acre-inch of liquid waste applied to tile drained plots of Amity sicl was approximately 90% (Figure 22).

Table 28. Total-N and NO_3-N concentration in drain tile effluents from Amity soil receiving dairy waste slurries with moisture criteria.

Application date	Treatment rate (acre-in. /plot)	Total-N effluent (ppm)			NO_3-N effluent (ppm)		
		Applied	Initial (1 hr)	Final (2 hr)	Applied	Initial (1 hr)	Final (2 hr)
10-4-71	0	0	3	I. S.	<0. 1	9. 0	I. S.
	1*	371	100	118	1. 2	0. 1	0. 2
	2**	371	190	150	1. 2	0. 8	0. 5
10-5-71	1	338	83	103	1. 4	0. 2	0. 3
10-6-71	0	0	2	I. S.	<0. 1	3. 2	I. S.
	1	332	78	I. S.	2. 0	0. 6	I. S.
	2	332	50	137	2. 0	0. 5	0. 3
10-7-71	1	413	64	104	0. 3	0. 8	0. 5
10-8-71	0	0	5	I. S.	<0. 1	11. 2	I. S.
	1	470	87	90	1. 2	0. 5	0. 6
	2	470	27	79	1. 2	4. 0	0. 3
10-9-71	1	376	77	98	0. 3	0. 2	1. 0
10-10-71	0	0	4	I. S.	<0. 1	10. 0	I. S.
	2	445	55	130	4. 0	5. 0	0. 7
10-11-71	1	329	75	90	<0. 1	0. 2	0. 5
10-12-71	0	0	4	I. S.	<0. 1	11. 8	I. S.
	2	339	100	131	<0. 1	2. 5	0. 4
10-13-71	1	363	122	124	1. 0	0. 8	1. 0
10-14-71	0	0	4	I. S.	<0. 1	10. 3	I. S.
	2	428	57	131	1. 0	0. 4	0. 4
10-16-71	0	0	6	I. S.	<0. 1	9. 2	I. S.
	1	315	68	63	1. 4	3. 7	0. 4
	2	315	61	76	1. 4	0. 5	0. 4
10-17-71	1	375	47	92	1. 4	0. 2	0. 2

*Applied daily with soil moisture criteria, 0. 1 bar tension.

**Applied every two days with no soil moisture criteria.

I. S. - Insufficient sample

Table 29. NH_4-N concentrations in drain tile effluent from Amity soil receiving liquid dairy waste with moisture criteria.

Application date	Application rate (acre/in. plot)	NH_4-N Applied (ppm)	Initial* (ppm)	Removed (%)	Final** [1 week] (ppm)
10-4-71	0	0	0	--	I. S.
	1[a/]	225	22	90	26
	2[b/]	225	90	60	54
10-5-71	1	204	21	90	25
10-6-71	0	0	0	--	I. S.
	1	175	15	91	I. S.
	2	175	19	89	37
10-7-71	1	205	22	89	20
10-8-71	0	0	0	--	I. S.
	1	300	18	94	29
	2	300	9	97	21
10-9-71	1	218	6	97	23
10-10-71	0	0	0	--	I. S.
	2	235	18	92	51
10-11-71	1	104	10	90	16
10-12-71	0	0	0	--	I. S.
	2	168	45	73	42
10-13-71	1	220	13	94	32
10-14-71	0	0	0	--	I. S.
	2	215	20	91	50
10-16-71	0	0	0	--	I. S.
	1	172	26	85	16
	2	172	26	85	38
10-17-71	1	229	21	91	20

a/ Applied daily with soil moisture criteria, 0.1 bar tension.

b/ Applied every two days with no soil moisture criteria.

* NH_4-N concentrations in samples 20 to 40 minutes after waste application.

** NH_4-N concentration in samples two hours after waste application.

I. S. - Insufficient sample.

The liquid waste began to pond on the plots after four to five applications of two acre-inches of the liquid slurry that were applied every two days. The ponds of waste remained between applications with no visible tile effluent flow. Ponds also developed on plots receiving one acre-inch of waste slurry after seven daily applications.

The effluent NO_3-N concentration from plots receiving one-inch of waste was < 4.0 ppm. The NO_3-N concentration in effluent from the control plots consistently exceeded 9.0 ppm (Table 28). High concentrations of NH_4-N and alpha amino acids in the waste product can denitrify the accumulated soil nitrates to form free N_2 gas (19).

In the initial water sample the total N concentration in tile effluent from plots which received two acre-inches of waste slurry every two days decreased from 190 ppm on 4 October, to 27 ppm on 8 October, 1971 (Table 28). The effluent NH_4-N concentration in the same sample was 90 ppm on 4 October and decreased to 20 ppm on 6 October (Table 29). The NH_4-N and total N concentrations were higher on 4 October due to soil surface cracks. The removal of NH_4-N by the Amity sicl soil ranged from 60-85% throughout the application period (Figure 21).

The effluent NO_3-N concentrations from the plots which received two acre-inches of waste slurry were < 4.0 ppm. The NO_3-N levels in the soild which received the waste applications were

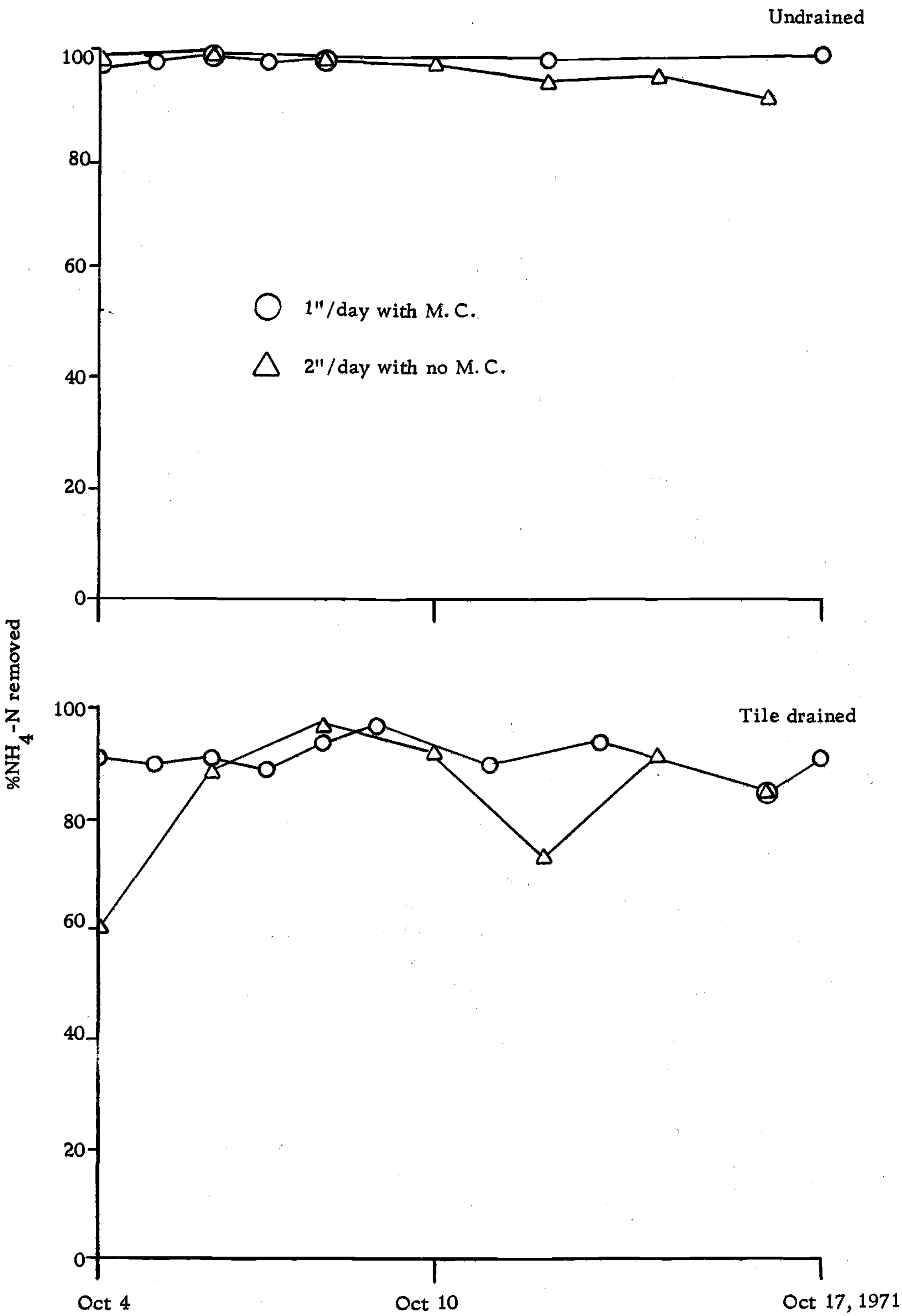


Figure 21. NH_4-N removed by desodded Amity sicl soil receiving dairy waste slurries as a function of moisture.

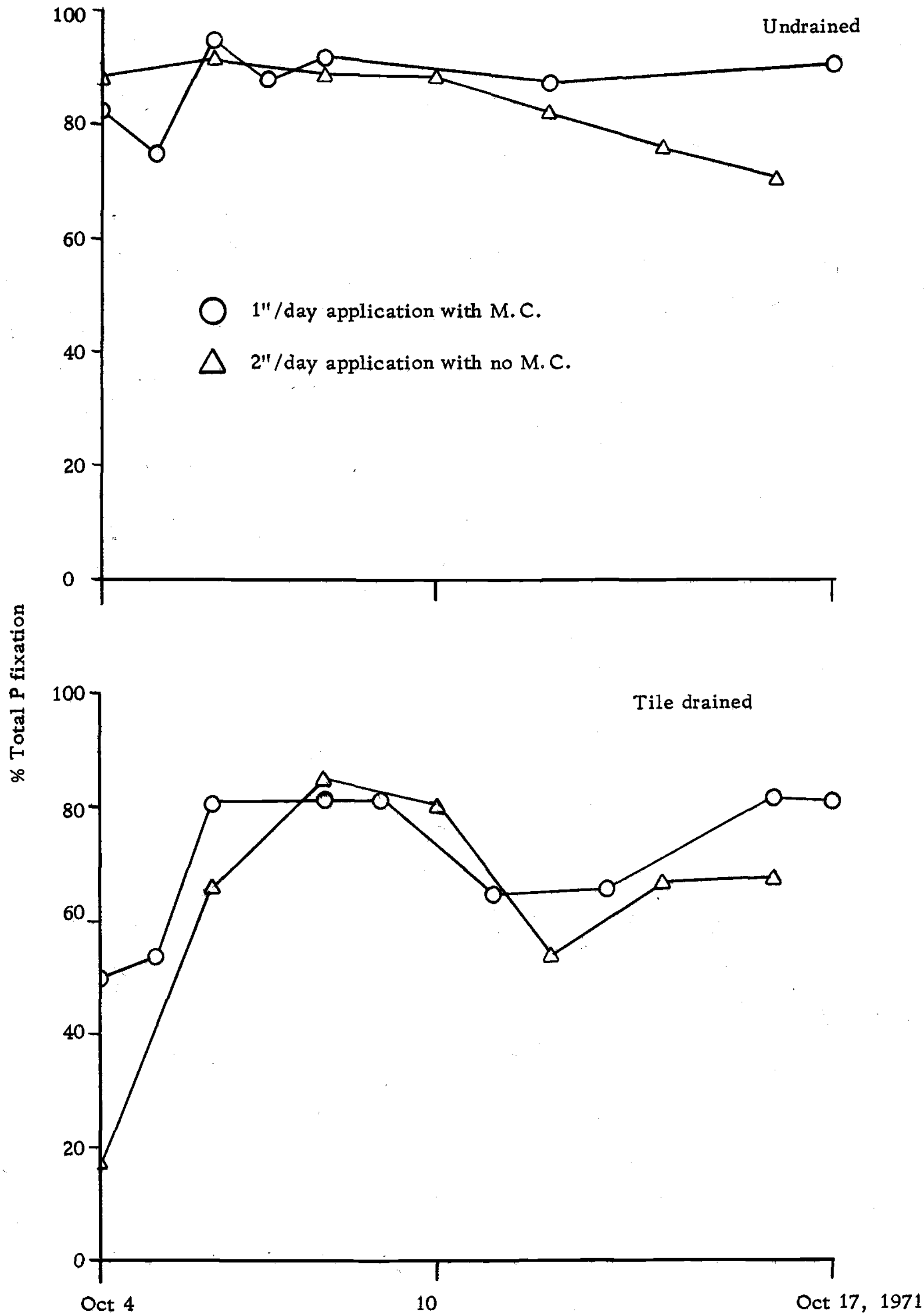


Figure 22. Total P fixation by desodded Amity sicl soil receiving dairy waste slurries as a function of moisture.

lower than the soils in the control plots. Denitrification processes evidently reduced NO_3-N present in the waste treated plots.

The total P concentration in the effluent, in the initial sample, from plots which received two acre-inches of waste slurry decreased from 142 ppm on 4 October to approximately 60 ppm for the remainder of the application period (Table 30). The total P fixed by Amity sicl soil from the application of two acre-inches of waste with no moisture criteria, was 18% on 4 October and increased to 85% four days later (Figure 22).

The total P concentration in the tile drain effluent from the plots which received waste only at >0.1 bar moisture tension levels, was 85 ppm on 4 October and was generally lower throughout the remainder of the application time (Table 30). The total P fixation by Amity sicl soil in plots receiving one acre-inch of liquid waste increased from 50% on 4 October and fluctuated between 65% and 85% throughout the application time (Figure 22). Phosphorus fixation on 4 October was low because the waste was applied to a dry soil which contained many surface cracks. The waste percolated rapidly through the profile. The phosphorus fixation increased for the later applications because the cracks did close upon wetting and reduced the infiltration and percolation rate.

In a study on anaerobic lagoon effluents Koeliker _et al._ (31) found that 95% of the applied waste phosphorus was fixed by the soil

Table 30. Phosphorus fixed by tile drained Amity sicl soil as a function of moisture.

Application date	Treatment rate (acre-in. /plot)	Total P Applied (ppm)	Total P Effluent* (ppm)	Total P Fixed (%)
10-4-71	0	0	1	-
	1[a]	175	85	50
	2[b]	175	142	18
10-5	1	155	70	54
10-6	0	0	2	-
	1	275	51	81
	2	275	92	66
10-7	1	225	72	67
10-8	0	0	2	-
	1	285	49	82
	2	285	42	85
10-9	1	265	45	82
10-10	0	0	2	-
	2	325	63	80
10-11	1	175	59	65
10-12	0	0	1	65
	2	175	79	54
10-13	1	235	79	66
10-14	0	0	2	-
	2	230	73	67
10-16	0	0	1	-
	1	180	30	82
	2	180	57	68
10-17	1	215	39	81

[a]/Applied daily with soil moisture criterion, 0.1 bar tension.

[b]/Applied every two days with no soil moisture criterion.

* Total P concentrations in samples 20 to 40 minutes after waste application.

when the waste was applied to tile drained field. No waste applications were performed if soil moisture tension exceeded 0. 15 bars. Koelliker also noted that 'short circuiting' of the lagoon waste effluent resulted when the waste was applied to saturated soils near the tile lines. The concentration of total P measured in the tile effluent was 75% of the applied material or approximately 25% total P fixation.

Groundwater From Undrained Plots

Waste ponds were observed on the plots which received the two acre-inches of liquid waste every two days with no moisture criteria after the fourth application.

The total-N concentration of the groundwater in the plots which received waste applications only when the moisture tension of the soil was > 0. 1 bar continuously decreased from 49 ppm on 4 October to 27 ppm on 17 October 1971 (Table 31). The total-N concentration of groundwater from plots which received two inches of waste and at any soil moisture content, increased from 33 ppm on 4 October to 76 ppm on 16 October 1971 (Table 31). Seepage may be a possible explanation for the differences in groundwater total-N concentration between the plots receiving one inch and two inches of waste. Seepage from the surface of ponded high application treatment plots into the sample wells would increase the groundwater total-N concentration.

Table 31. Total-N and NO_3-N concentration in groundwater from undrained Amity soil receiving dairy waste slurries with moisture criteria.

Application date	Treatment rate (acre-in. / plot)	Total-N Applied (ppm)	Total-N Groundwater* (ppm)	NO_3-N Applied (ppm)	NO_3-N Groundwater* (ppm)
10-4-71	0	0	2	<0.1	9.8
	1[a/]	371	49	1.2	0.2
	2[b/]	371	33	1.2	0.3
10-5-71	1	338	38	1.4	8.0
10-6-71	0	0	3	<0.1	13.3
	1	332	23	1.7	28.0
	2	332	50	1.7	0.1
10-7-71	1	413	43	0.3	4.1
10-8-71	0	0	3	<0.1	14.5
	1	470	39	1.2	16.0
	2	470	64	1.2	0.3
10-10-71	0	0	5	<0.1	14.5
	2	445	54	3.6	0.2
10-12-71	0	0	4	<0.1	14.7
	1	339	36	<0.1	5.0
	2	339	68	<0.1	1.4
10-14-71	0	0	5	<0.1	15.2
	2	428	57	0.8	0.4
10-16-71	0	0	5	<0.1	14.4
	2	315	76	1.1	0.2
10-17-71	1	375	27	1.4	5.2

[a/] Applied daily with soil moisture criteria, 0.1 bar tension.

[b/] Applied every two days with no soi. moisture criteria.

*Total-N and NO_3-N concentrations in samples collected one day after waste application.

The groundwater NO_3-N concentrations from plots that received one inch of waste with soil moisture tension of >0.1 bar ranged from 0.2 to 28.0 ppm (Table 31).

No important ground water NH_4-N concentration differences occurred between plots that received one inch of waste with moisture criteria and plots receiving two inches of waste with no moisture criteria until 8 October 1971 (Table 32). At that time, groundwater NH_4-N concentration from plots that utilized no moisture criteria increased from 9.0 on 8 October, to 16.0 ppm on 16 October. The NH_4-N concentration in plots that utilized moisture criteria in waste application ranged consistently between 3.0 and 5.0 ppm. Groundwater NH_4-N concentrations from plots that received no waste treatment remained < 1.0 ppm (Table 32). Surface ponding and NH_4-N contamination of the sample waters occurred. The removal of NH_4-N from waste slurry applications was >90% (Figure 21).

The groundwater total P concentration one day after the application of one inch of waste to soil with soil moisture tensions of >0.1 bar did not exceed 40 ppm and was consistently between 20 and 30 ppm (Table 33). The groundwater total P concentration from plots that received two inches of waste and no soil moisture criteria increased from 22 ppm on 4 October to 53 ppm on 16 October (Table 33).

The total P fixation by Amity sicl soil that received one inch of

Table 32. Groundwater NH_4-N concentration in undrained Amity soil receiving dairy waste slurries as a function of moisture.

Application date	Treatment rate (acre-in. /plot)	NH_4-N Applied (ppm)	NH_4-N Groundwater* (ppm)	NH_4-N Removed (%)
10-4-71	0	0	0	-
	1[a/]	225	7	97
	2[b/]	225	4	98
10-5-71	1	204	4	98
10-6-71	0	0	0	-
	1	175	2	99
	2	175	4	98
10-7-71	1	208	5	98
10-8-71	0	0	0	-
	1	300	3	99
	2	300	9	97
10-10-71	0	0	0	-
	2	234	7	97
10-12-71	0	0	0	-
	1	168	3	98
	2	168	11	94
10-14-71	0	0	0	-
	2	215	12	95
10-16-71	0	0	0	-
	2	172	16	91
10-17-71	1	229	3	99

[a/] Applied daily with soil moisture criteria, 0.1 bar tension.

[b/] Applied every two days with no soil moisture criteria.

* NH_4-N concentration in samples one day after waste application.

Table 33. Phorphorus fixation by undrained Amity soil receiving dairy waste slurries as a function of moisture.

Application date	Treatment rate (acre-in./plot)	Applied (ppm)	Groundwater* (ppm)	Fixed (%)
10-4-71	0	0	2	-
	1[a/]	175	30	83
	2[b/]	175	21	88
10-5	1	155	39	75
10-6	0	0	2	-
	1	275	13	95
	2	275	22	92
10-7	1	225	26	88
10-8	0	0	3	-
	1	285	22	92
	2	285	32	89
10-10	0	0	3	-
	2	325	43	88
10-12	0	0	4	-
	1	175	21	88
	2	175	31	82
10-14	0	0	4	-
	2	230	53	77
10-16	0	0	2	-
	2	180	53	71
10-17	1	215	20	91

[a/] Applied daily with soil moisture criteria, 0.1 bar tension.

[b/] Applied every two days with no soil moisture criteria.

*Total P concentrations in samples one day after waste application.

waste remained fairly constant with 90% fixation. Minimum total P fixation by Amity sicl soil that received two inches of waste decreased from 90% on 10 October to 71% on 16 October 1971 (Figure 22). Sample well contamination may have occurred with a resultant erroneous total P fixation percentage for the soil in the plots which received two inches of waste with no soil moisture criteria.

Total Nitrogen Applications and Losses

To calculate nitrogen accumulations on the plots the following assumptions were made: (a) Quantity of waste applied to the soil equalled the drainage effluent. b) The effluent total-N concentration was linear with time.

The total-N removed by the soil in the drained plots which received two inches of waste totaled 764 pounds per acre of the 1007 pounds per acre applied. Approximately 500 pounds of total-N was removed by the Amity sicl soil which received the one inch of waste according to moisture criteria. A total of 613 pounds per acre of total-N was applied (Table 34). The plots that received one inch of waste if the soil moisture tension was >0.1 bar removed a higher percentage of total-N, but the plots that received two inches of waste and no soil moisture criteria disposed more pounds per acre of total-N.

The Amity sicl soil in the undrained plots which received two

Table 34. Fall application of dairy cow waste slurries to tile drained Amity soil.

Application date	Total-N				NH_4-N Applied		Total P Applied		Total solids Applied	
	Applied		Removed							
	lbs/acre									
Sod	A*	B	A	B	A	B	A	B	A	B
10-4-71	67	134	47	72	41	82	32	63	1330	2660
10-5-71	61	-	44	-	37	-	28	-	1477	--
10-6-71	60	120	46	86	32	63	50	100	1336	2672
10-7-71	75	-	57	-	37	-	41	-	1503	--
10-8-71	85	170	69	150	54	109	52	103	3172	6345
10-9-71	68	-	51	-	39	-	48	-	1325	--
10-10-71	-	161	-	128	-	85	-	118	--	2854
10-11-71	60	-	45	-	19	-	32	-	1523	--
10-12-71	-	123	-	88	-	61	-	63	--	5780
10-13-71	65	-	43	-	40	-	43	-	869	--
10-14-71	-	155	-	121	-	78	-	83	--	2165
10-16-71	72	144	62	119	31	62	33	65	706	1412
10-17-71	68	-	54	-	41	-	39	-	672	--
Total	613	1007	518	764	371	540	398	595	13713	23888

*A = one acre inches application rate (150 gal/plot), moisture criterion < 0.1 bar.
B = two acre inch application rate (300 gal/plot), no moisture criterion.

inches of waste adsorbed 859 of the 1007 pounds per acre of total-N applied. The total-N removal by Amity sicl soil in the plots receiving one acre-inch of waste each day with the moisture criteria amounted to 421 of the 477 pounds per acre applied (Table 35). The relative percentage of total-N removal was the same for the two waste application treatments. The waste application of two inches with no soil moisture criteria, however, allowed disposal of twice as much dairy waste.

The undrained plots which received one inch of waste when the moisture content was low, >0.1 bar, received approximately one-half of the scheduled 14 applications of waste. The tile drained plots with the same application criteria received 10 of the 14 scheduled waste applications.

Vegetative Growth on Sod Covered Plots

Pasture species growing on the experimental plots included fescue, rye grass, and New Zealand clover. During the growing season, March through October, luxurious growth occurred on the plots that received the dairy cow waste slurries. As waste solids accumulated through the growing season, especially on the plots receiving the high waste application the clover was smothered and grass growth hindered.

The heights, color and density of the grass and clover in the

Table 35. Fall application of dairy cow waste slurries to undrained Amity soil.

Application date	Total-N Applied		Total-N Removed		NH_4-N Applied		Total P Applied		Total solids Applied	
	lbs/acre									
Sod	A*	B	A	B	A	B	A	B	A	B
10-4-71	67	134	58	121	41	82	32	63	1330	2660
10-5-71	61	-	54	-	37	-	28	-	1477	--
10-6-71	60	120	56	102	32	63	50	100	1336	2672
10-7-71	75	-	57	-	37	-	41	-	1503	--
10-8-71	85	170	78	147	54	109	52	103	3172	6345
10-10-71	-	161	-	141	-	85	-	118	--	2854
10-12-71	61	123	55	98	31	61	32	63	2390	5780
10-14-71	-	155	-	134	-	78	-	83	--	2165
10-16-71	-	144	-	116	-	62	-	65	--	1412
10-17-71	68	-	63	-	41	-	39	-	672	--
Total	477	1007	421	859	273	540	274	595	11880	23888

*A = one acre inch application rate (150 gal/plot), soil moisture criteria, < 0.1 bar tension.
B = two acre inch application rate (300 gal/plot), no moisture criterion.

plots which received the medium waste treatment was improved over the control plots which received no waste applications.

Nitrogen and Phosphorus Accumulation in Dairy Waste Treated Soils

Nitrogen

The total-N, NH_4-N and NO_3-N data was evaluated to determine nitrogen accumulation in the soil. Arithmetic means for soil nitrogen analysis were calculated by averaging data from the sodded and desodded plots for each application rate and drainage treatment. Nitrogen accumulations were calculated in this manner for a 0 to 12" and 22 to 28" soil depth. The measurement of nitrogen accumulation or loss was for a one year period, November 1970 to November 1971.

Total Nitrogen

Total-N applied to the soil surface accumulated more in the surface 12 inches than the 22 to 28 inch sample depth (Table 36). The total-N content of the surface soil, 0 to 12 inch depth, in the tile drained plots which received the high waste application increased from 3740 to 4660 pounds per acre in August 1971. Total-N applied during this interval was 2035 pounds per acre. The total-N content of the surface soil then decreased to 4000 pounds per acre in November, although 2380 pounds per acre were applied in September

Table 36. Soil total nitrogen (lb/acre) after additions of liquid dairy waste.*

	Soil sample depth (in.)	Initial soil	March 1971		May 1971		August 1971		September 1971		November 1971		Total applied
			Applied	Soil	Applied	Soil	Applied	Soil	Applied	Soil	Applied	Soil	
						Drainage tiled							
Control	0-12	3740	0	3810	0	3670	0	4040	0	4200	0	3700	0
	22-28	1240		1190		1230		1120		1140		1280	
Medium	0-12	3740	330	4120	230	4300	288	4880	611	4740	890	4340	2349
	22-28	1240		1180		1100		930		1400		1160	
High	0-12	3740	728	3800	585	4600	722	4660	1400	4270	980	4000	4415
	22-28	1240		1260		1190		1250		1380		1220	
						Untiled							
Control	0-12	3740	0	4200	0	4260	0	4260	0	4360	0	4200	0
	22-28	1240		1210		1270		1190		1270		1540	
Medium	0-12	3740	330	4060	230	4170	288	4980	611	4580	890	3740	2349
	22-28	1240		1440		1270		1370		1260		1480	
High	0-12	3740	728	3760	585	4420	722	4420	1400	4340	980	4260	4415
	22-28	1240		1330		1120		1210		1170		1240	

*Composite of sod covered and desodded treatments.

and November, 1971 (Table 35). The net accumulation of total-N in the soil surface for the tile drained plots which received the high waste application was only 260 pounds per acre, while over 4415 pounds of total-N in the subsoil, 22 to 28 inches, of the tiled plots, remained constant, 1240 to 1400 pounds per acre, even though 2349 to 4415 pounds per acre of total-N was applied (Table 36). The applied wastes percolated rapidly through the subsoil and left essentially no residual nitrogen. The subsoil total-N content was similar for the undrained plots. The low net accumulations of total-N can be attributed to large N losses in the tile drain effluents. Ammonia nitrogen losses may also account for substantial total N loss.

Ammonium Nitrogen

The NH_4-N recovered from soils in the tile drained and untiled plots which received the waste applications was low. Initial NH_4-N levels in the soil were 1.0 pound per acre in both sampled horizons (Table 37). Ammonium N applications totaled 1124 and 2111 pounds per acre, respectively for the plots receiving the medium and high waste applications. The final NH_4-N level in the surface soil of the untiled Amity soil ranged from 11.0 to 14.0 pounds per acre regardless of waste treatment. Subsoil NH_4-N contents remained relatively constant even after the waste applications (Table 37).

Table 37. Soil NH_4-N (lb/acre) after additions of liquid dairy waste.*

	Soil Sample depth (in.)	Initial soil	March 1971		May 1971		August 1971		September 1971		November 1971		Total applied
			Applied	Soil	Applied	Soil	Applied	Soil	Applied	Soil	Applied	Soil	
						Drainage tiled							
Control	0-12	1.0	0	2.5	0	5.8	0	8.0	0	17.0	0	3.0	0
	22-28	1.0		2.0		3.1		3.4		6.5		8.0	
Medium	0-12	1.0	108	4.0	58	5.1	146	7.6	282	11.0	530	18.0	1124
	22-28	1.0		5.0		4.8		2.2		5.5		5.0	
High	0-12	1.0	282	5.5	156	2.7	394	8.5	749	12.5	530	14.0	2111
	22-28	1.0		1.0		3.5		6.3		6.5		3.0	
						Untiled							
Control	0-12	1.0	0	1.0	0	3.8	0	5.4	0	15.5	0	14.0	0
	22-28	1.0		1.0		5.8		11.0		7.0		3.0	
Medium	0-12	1.0	108	4.0	58	4.4	146	7.2	282	29.8	530	12.0	1124
	22-28	1.0		3.0		5.8		6.3		6.5		2.0	
High	0-12	1.0	282	5.5	156	5.8	394	8.0	749	14.5	530	14.0	2111
	22-28	1.0		3.0		2.7		3.4		4.5		3.0	

*Composite of desodded and sod covered treatments.

Two possible losses of soil NH_4-N, besides volatilization at application, are rapid nitrification and clay lattice fixation. Adsorbed NH_4-N can be nitrified within 24 hours. Ammonium-N can be fixed within the lattice structure of the smectite and vermiculite clays present in the Amity sicl soil. The fixed NH_4-N is not extracted by the potassium chloride extraction procedure (35).

Nitrate Nitrogen

The NO_3-N concentration in the soil fluctuated with the changes in microbiological activity. The NO_3-N in the surface soil in the tile drained plots which received the high waste application increased from 2.0 ppm to 32.5 ppm during August 1971 (Table 38). The soil NO_3-N concentration then decreased to 1.5 ppm in November 1971. Nitrate nitrogen levels in the subsoil remained constant at < 2.0 ppm.

The NO_3-N concentration in the surface soil from the tile drained plots which received the medium waste application increased from 2.0 ppm on August 1970, to 35.0 ppm on September 1971. The NO_3-N in the surface soil decreased to 8.0 ppm in November 1971. The subsoil NO_3-N concentration increased from < 0.1 ppm, prior to waste application, to 15.5 ppm on the November 1971 sample date (Table 38).

The NO_3-N concentration in the soil from the undrained plots which received the medium waste application increased from 2.0 ppm

Table 38. Soil NO_3-N concentration (ppm) after additions of liquid dairy wastes.*

	Soil sample depth (in.)	Application rate (gal/plot)	Soil NO_3-N					
			Initial	March 1971	May 1971	August 1971	September 1971	November 1971**
			Drainage tiled					
Control	0-12	0	2.0	4.5	5.2	9.3	15.2	22.0
	22-28		<0.1	2.2	1.1	0.4	4.5	10.0
Medium	0-12	400	2.0	3.5	5.8	22.3	35.0	8.0
	22-28		<0.1	3.0	1.3	1.3	9.5	15.5
High	0-12	1000	2.0	5.8	1.7	32.5	13.0	1.5
	22-28		<0.1	1.5	0.8	1.9	1.0	<0.1
			Untiled					
Control	0-12	0	2.0	9.7	2.7	9.5	4.7	11.5
	22-28		<0.1	2.2	0.4	2.1	2.5	9.5
Medium	0-12	400	2.0	3.5	3.2	11.1	46.7	21.5
	20-28		<0.1	<0.1	1.0	1.7	8.2	15.0
High	0-12	1000	2.0	9.5	3.8	24.8	29.5	3.0
	22-28		<0.1	0.8	0.8	1.1	2.5	<0.1

*Composite concentration of desodded and sod covered treatments.

**Soil NO_3-N concentrations after additions of 0, 1 and 2 acre-inch.

on the initial sample to 46.7 ppm in September and decreased to 21.5 ppm on November 1971 (Table 38).

The decrease in NO_3-N concentration between September and November 1971 in the surface soil of both drainage treatments which received the waste application could result from NO_3-N leaching and denitrification processes. The NO_3-N that was leached into the subsoil of undrained plots probably was denitrified in the anaerobic environment of the subsoil.

Total Phosphorus

The total-P recovered in the surface soil in the tile drained plots receiving the high waste applications increased from 3800 pounds per acre to 6060 pounds per acre (Table 39). The total-P content of the surface soil in drained plots that received the medium waste application increased from 3800 pounds per acre to 4760 pounds per acre in November 1971 after application of 1173 pounds of total-P per acre.

The total-P in the surface soil of the undrained plots which received the high waste application (2847 pounds total P per acre) increased from 3800 pounds per acre to 6380 pounds per acre in November 1971 (Table 39). The total-P content of the Amity sicl soil that received the medium waste application rate increased to 4680 pounds per acre after 1173 pounds were applied.

Table 39. Phosphorus fixation in Amity sicl soil receiving liquid dairy wastes.

	Total P (lb/acre)				
	Initial soil	May 1971		November 1971	
		Applied	Soil	Applied	Soil
Drainage Tile					
0-12	3800	273	4180	900	4760
22-28	2500		1860		2360
0-12	3800	683	4120	2164	6060
22-28	2500		2220		1960
Undrained					
0-12	3800	273	3980	900	4680
22-28	2500		2400		2660
0-12	3800	683	4360	2164	6380
22-28	2000		2360		2600

Ninety percent of the total P fixation occurred in the surface soil. The remaining total P was lost in the percolated effluent. Undrained Amity sicl soil fixed more phosphorus, 6400 pounds per acre, as compared to 6100 pounds per acre for tile drained plots. The higher fixation at the high application rate was probably due to an increase in soil-liquid waste contact time in the undrained plots as compared to tile drained plots. Channelization of the tile trench backfill was a major factor that resulted in the reduced soil-liquid contact time in the tile drained plots. The 10 to 20% loss of total P exceeded normal P losses through solubilization. Generally less than 5% of applied P is lost with percolation waste.

Animal Waste Application to Agricultural Tiled Soil

The waste disposal studies previously discussed were conducted on narrow spaced tiled and untiled Amity sicl soil. An additional study was established to determine water quality in the tile effluent from an agricultural tiled soil.

Cumulative Nitrogen, Phosphorus and Dry Matter Application

Dry Matter

Average cumulative dry matter applied to the test area was 25,500 pounds per acre (Table 40). The northeast and northwest

Table 40. Liquid dairy cow waste solids, nitrogen and phosphorus applied to an agricultural tiled Amity soil.

Quadrant section	Total-N (lb/acre)	NH_4-N (lb/acre)	Total-P (lb/acre)	Dry matter (lb/acre)
NW	3310	1530	1340	30270
NE	3100	1430	1260	28500
SW	2300	1060	930	20500
SE	2640	1220	1070	23170
Average	2840	1310	1150	25500

quadrants in the study area received 30, 270 and 28, 500 pounds per acre, respectively. The southern quadrants, southeast and southwest, received 23, 170 and 20, 050 pounds per acre, respectively. The south-southwest prevailing wind during the application times caused the higher waste applications to the northern two quadrants (Figure 23).

Nitrogen and Phosphorus

The average cumulative total-N in the applied animal waste was 2840 pounds per acre (Table 40). The average cumulative NH_4-N applied was approximately 50% of the total N and the total P applied averaged 1150 pounds per acre.

Groundwater Nitrogen and Phosphorus After One Application Period

Nitrogen

The total N concentration in the groundwater increased from 1. 5 ppm before waste application to 4. 0 ppm after one waste application (Table 41). The NH_4-N concentrations did not increase with the initial waste application (Table 41). The applied NH_4-N was adsorbed by the soil and did not move down the soil profile.

The NO_3-N concentrations in the groundwater adjacent to the lateral tile line was 14. 4 ppm on 25 January 1971. The NO_3-N in the

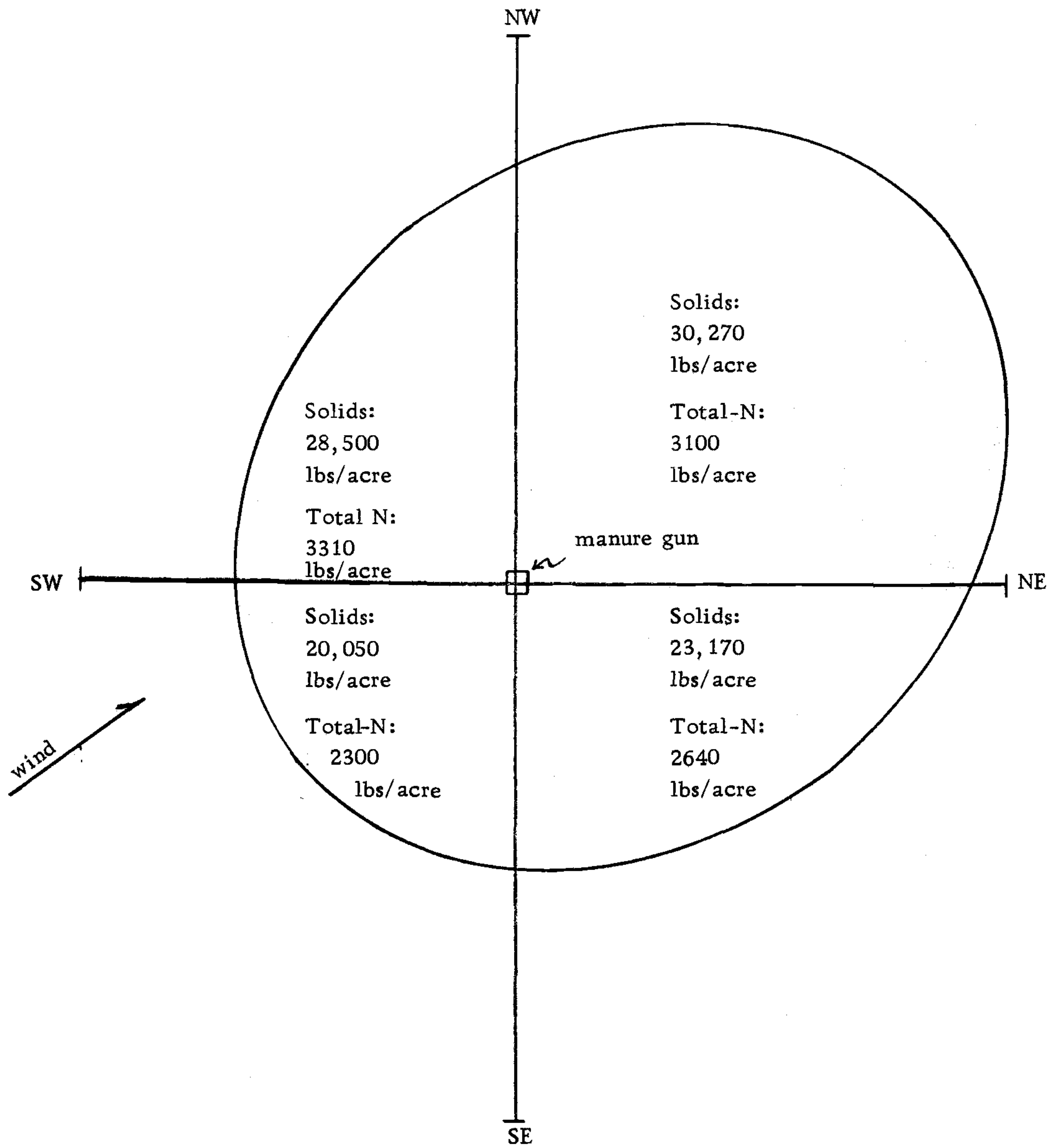


Figure 23. Cumulative dry matter waste application pattern to agricultural tiled soil.

Table 41. Nitrogen and phosphorus concentrations in groundwater.

Sample date	Sample area*	Total-N (ppm)		NH_4-N (ppm)		NO_3-N (ppm)		Total-P (ppm)	
		Applied	Ground-water	Applied	Ground-water	Applied	Ground-water	Applied	Ground-water
1-25-72	BTL		1		1		3		>0.1
	LTL		1		0		15		>0.1
	MTA				1		0		0.2
1-26-72	BTL	420	2	195	0	2	1	182	>0.1
	LTL	420	1	195	0	2	10	182	>0.1
	MTA	420	1	195	1	2	0	182	>0.1
1-27-72	BTL		4		1		1		0.2
	LTL		3		1		8		0.3
	MTA		3		0		0		0.2
1-28-72	BTL		4		0		1		0.2
	LTL		5		2		8		0.1
	MTA		3		1		1		>0.1
1-29-72	BTL		3		1		1		0.1
	LTL		4		1		6		0.3
	MTA		4		1		0		0.1
1-30-72	BTL		4		1		2		0.1
	LTL		4		1		11		0.2
	MTA		4		1		1		0.1

*BTL - Base Tile Line; LTL - Lateral Tile Line; MTA - Mid Tile Area water probably resulted from nitrification of NH_4-N that was applied the previous summer. The NO_3-N concentration in this groundwater decreased with the application of manure and rainfall (Figure 24). The NO_3-N concentration in the groundwater midway between tile lines remained < 1.0 ppm NO_3-N during and after the waste application (Table 41) (Figure 24).

Phosphorus

The total P concentration in the groundwater did not exceed 1.0 ppm (Tables 41 and 42). These results concur with those of Koelliker *et al.* (31) who observed the reduction of total P from 72 ppm in animal waste to < 1.0 ppm in tile effluents after the waste slurry had been applied to a land surface.

Groundwater Nitrogen and Phosphorus After Seven Application Periods

Nitrogen

Two weeks following the initial waste application, seven additional applications of liquid manure were made. Groundwater samples were collected on 14 February 1972, before applications were made, and continued for ten days.

The total-N concentration in the groundwater increased from 2.0 ppm on 14 February to 6.0 ppm on 21 February (Table 42),

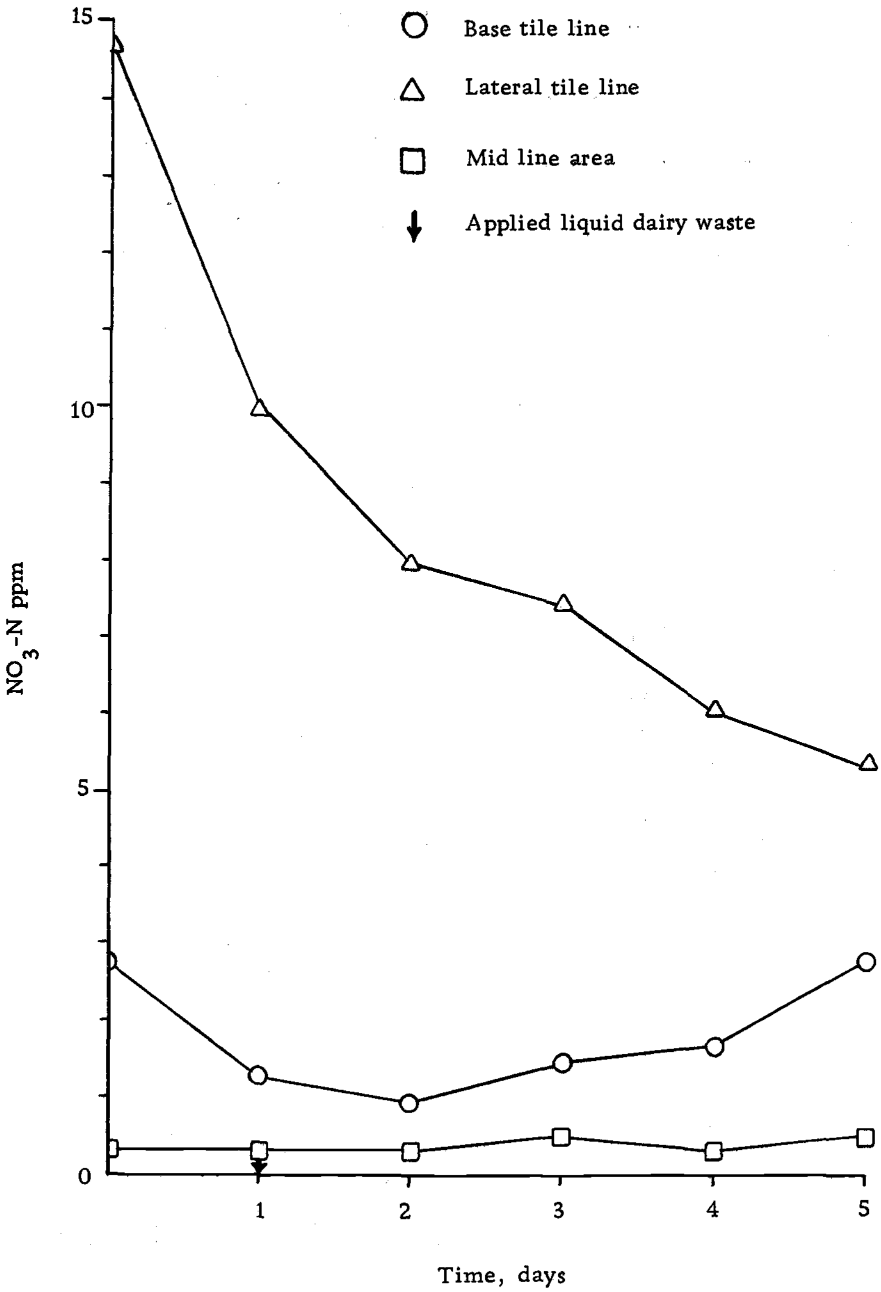


Figure 24. NO_3-N concentration of groundwater in agricultural tiled Amity soil.

Table 42. Nitrogen and phosphorus in groundwater of an agricultural tiled soil treated with animal waste.

Sample date	Sample area*	Total-N (ppm)		NH_4-N (ppm)		NO_3-N (ppm)		Total-P (ppm)	
		Applied	Ground-water	Applied	Ground-water	Applied	Ground-water	Applied	Ground-water
2-13-72	BTL	420		198		0.5		210	
	LTL	420		198		0.5		210	
	MTA	420		198		0.5		210	
2-14-72	BTL	436	3	192	1	1.0	3	162	>0.1
	LTL	436		192	2	1.0	8	162	>0.1
	MTA	436	2	192	1	1.0	0	162	>0.1
2-15-72	BTL	390	4	211	2	0.6	2	180	>0.1
	LTL	390	2	211	1	0.6	12	180	>0.1
	MTA	390	3	211	1	0.6	0	180	>0.1
2-16-72	BTL	430	3	180	1	2.4	0	165	0.2
	LTL	430	2	180	1	2.4	8	165	0.1
	MTA	430	3	180	1	2.4	1	165	0.1
2-17-72	BTL	425	3	177	1	0.6	0	190	0.3
	LTL	425	2	177	1	0.6	8	190	0.2
	MTA	425		177	1	0.6		190	>0.1
2-18-72	BTL	420		202	1	2.0	0	150	0.3
	LTL	420		202	0	2.0	4	150	0.3
	MTA	420	4	202	1	2.0	<0	150	0.3
2-19-72	BTL	415	6	195	0	0.6	0	134	0.1
	LTL	415		195		0.6		134	0.2
	MTA	415	5	195	0	0.6	0	134	0.1
2-21-72	BTL		6		0		0		0.4
	LTL		5		1		0		0.2
	MTA		5		0		0		

*BTL - Base Tile Line; LTL - Lateral Tile Line; MTA - Mid Tile Area after all waste applications had been completed.

The NH_4-N in the groundwater from the three sampling areas remained close to 1.0 ppm (Table 42). The NH_4-N concentration was considerably less than those recorded for the waste disposal studies involving the 5 foot tile spacing. Preferential water flow through soil tunnels did not occur as readily in the soil tiled at the 62 ft. spacing.

The NO_3-N concentration decreased from 3.0 to 11.0 ppm, after the second sample collection day on 15 February, to < 1.0 ppm on 21 February in the groundwater adjacent to the lateral tile lines (Table 42). The NO_3-N concentration in the groundwater between the tile lines was < 1.0 ppm throughout the period of seven applications (Figure 25).

Phosphorus

The total P concentration in the groundwaters remained < 0.1 ppm for the three sample areas during the first two sampling dates, February 14 and 15. The total P concentrations increased after 16 February from 0.2 to 0.5 ppm on 23 February 1972 (Table 42). Over 99% of the total P applied from the waste slurries was fixed by the Amity sicl soil.

The results seem to be more representative of a field agricultural tile situation. The problem of soil surface cracking and

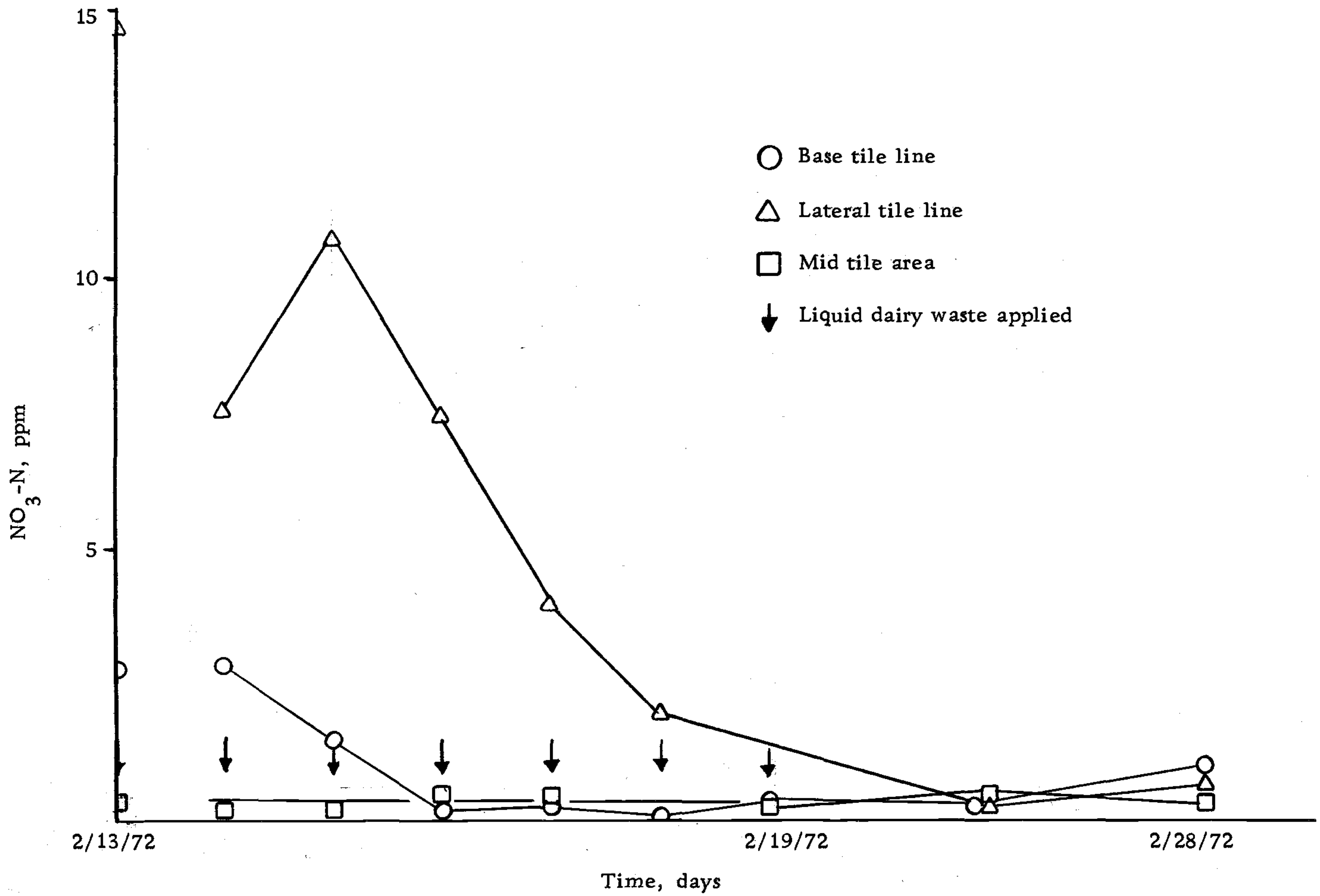


Figure 25. NO_3-N concentration of groundwater in agricultural tiled soil which received seven waste applications.

tile backfill tunneling were not reflected in the groundwater concentrations.

Groundwater pollution did not occur with NH_4-N or total P since the concentrations were < 5.0 ppm and < 1.0 ppm, respectively. But possible pollution of the groundwaters by NO_3-N did occur since the NO_3-N concentration did occasionally exceed 15 ppm. The total-N, NH_4-N and total P concentration remained relatively constant at all sample points.

SUMMARY AND CONCLUSIONS

Animal wastes in the past have been used as fertilizers and soil amendments since man first domesticated livestock. Disposal of the wastes was no problem. But, lately, due to the use of commercial fertilizers and strong environmental protection laws, solid waste disposal has become a problem.

In this research project, water quality changes were measured after application of liquid dairy waste to tile drained and undrained Amity sicl soil.

Waste application of 0, 400 and 1000 gallons of liquid waste per plot were applied during the winter, summer and fall of 1971. Applications were made monthly during the winter and semi-monthly during the summer. After the winter of 1971, the tile backfill was tamped to seal preferential water channels.

The fall 1971 waste applications which included moisture criteria were applied daily for two weeks.

In a second study area one to two acre-inches of liquid waste were applied daily to the agricultural tiled soil.

Dairy cow waste slurries were characterized for total solids, total-N, total P, NH_4-N and NO_3-N content. The concentration of N and P in liquid dairy cow wastes decreased in the winter months due to dilution of the waste by winter storm water and excess barn alley-way flush water and variations in the dairy cow feed program.

The total-N, total P, and NH_4-N concentration in the tile drain effluent were high for application rates after waste application to the tiled plots in the winter and summer of 1971. The total-N, total P and NH_4-N concentration in the tile effluent was 9 to 250 ppm during the winter application because of the presence of channels in the tile backfill. The problem still existed during the following summer after the backfill had been packed, but to a lesser degree.

The total-N, total P and NH_4-N concentration in the groundwater from undrained plots which received the waste were 120 to 450 ppm, probably due to inadequate seals around the sample tubes.

The NO_3-N concentration in the tile effluent and groundwater increased from 1.0 to 8.4 ppm during the winter to summer due to the increased microbiological activity.

The use of soil moisture criteria for waste application did not improve water quality. The total-N, total P and NH_4-N concentrations did decrease in the tile effluent with time as the result of the surface waste accumulation and subsequent reduced water percolation rate. The reduced infiltration rate allowed for improved liquid waste-soil contact.

When the waste was applied to the agricultural tiled soil, the soil removed 95 to 99% of the total-N, total P and NH_4-N. The NO_3-N concentration observed in the groundwaters probably related to waste applications during the previous year. The problem of internal channels in the tile backfill was not apparent.

Accumulations of N and P in the Amity sicl soil from applications of liquid dairy wastes to the research plots occurred mainly in the surface 12 inches. The total-N accumulations for both waste application rates were lower than anticipated. Accumulations were low due to the rapid percolation of wastewater through the soil and thus insufficient soil-waste contact time. The N and P content of the subsoil, 22 to 28 inch depth, remained relatively constant.

The NO_3-N concentration in the 0 to 12 inches layer of the Amity soil increased during the summer and decreased during the fall because of leaching and cooler soil temperatures. The subsoil NO_3-N concentrations increased during the fall. Drained plots appeared to have slightly less denitrification in the subsoil than the undrained plots.

Ninety percent of the total P fixation occurred in the surface 12 inches of the Amity sicl soil.

Vegetation cover did not appear to have an important effect on the N and P removed from the applied waste. If applications were made to steeper slopes, 7 to 12%, vegetation cover would possibly be an important factor.

The five foot tile spacing used in the research plots would have functioned if sufficient care was used in the replacement of the tile trench backfill. The study of the agricultural tiled soil with the 62 foot tile spacing proved to be more practical. Suggested application rates would be one acre-inch per day of $< 2\%$ total solids in the dairy slurry. The system should be moved daily with a minimum of a three week cycle to the same location to prevent the formation of a manure thatch.

BIBLIOGRAPHY

1. Adriano, D. C., P. F. Pratt and S. E. Bishop. Fate of inorganic form of N and salt from land-disposal manures from dairies. Livestock Waste Management and Pollution Abatement. American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 243-246. 1971.

2. Alexander, M. Nitrification. Soil Nitrogen, ed. W. B. Bartholomew and F. E. Clark. American Society of Agronomy Monograph #10, Madison. p. 203-240. 1965.

3. American Public Health Association. Standard methods for the examination of water and waste-water. 12th ed. New York, Boyd. 1965. 769 p.

4. Anderson, G. and E. Z. Arlidge. The adsorption of inositol phosphates and glycerophates by soil clays, clay minerals and hydrated sesquioxides in acid media. Journal of Soil Science 13:216-220. 1962.

5. Anthony, W. B. Utilization of animal wastes as feed for ruminants. Management of Farm Wastes, American Society of Agricultural Engineers Pub. SP-0366, St. Joseph, Mich. p. 109-111. 1966.

6. ________________. Cattle manure as feed for cattle. Livestock Waste Management and Pollution Abatement. American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 293-296. 1971.

7. Bailey, G. W. Role of soils and sediment in water pollution control. I. Reactions of nitrogen and phosphorus compounds with soils and geological strata. U. S. Dept. of Interior, Federal Water Pollution Control Admin. Southeast Waste Laboratory. 1968. 60 p.

8. Bailey, G. W. and J. L. White. Review of adsorption and desorption of organic pesticides by soil colloids with implication concerning pesticide bioactivity. Journal of Agricultural Food Chemistry 12:324-502. 1964.

9. Bartlett, H. D. and L. F. Mariott. Subsurface disposal of liquid manure. Livestock Waste Management and Pollution Abatement. American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 293-296. 1971.

10. Bradfield, R. Liebig and the chemistry of the soil. Liebig and after Liebig, ed. F. R. Moultan. American Association for the Advancement of Science, Science Press. p. 48-63. 1949.

11. Bremner, J. M. and K. Shaw. Denitrification in soil. II. Methods of investigation. Journal of Agricultural Science 51:40-51. 1958.

12. Broadbent, F. E. and F. E. Clark. Denitrification. Soil nitrogen, ed. W. V. Bartholomew and F. E. Clark. American Society of Agronomy Monograph #10, Madison. p. 275-315. 1965.

13. Buckman, H. O. and N. C. Brady. The nature and properties of soils. 7th ed. New York, Macmillan, 1965. 653 p.

14. Buswell, A. M. and B. F. Dudenbostel. Spectroscopic studies of base exchange materials. Journal of American Chemistry Society 63:2554-2559. 1941.

15. Cross, O. E. and E. A. Olson. Livestock liquid manure disposal systems. Omaha, 1968. 15 p. (Extension Service, University of Nebraska, College of Agriculture and Home Economics and U. S. Dept. of Agriculture cooperating. E. C. 68-776)

16. Fokin, A. D. and E. D. Christova. Effect of humic substances on phosphate sorption by soils. Soils and Fertilizers 28:2209. 1964.

17. Forbes, E. B. et al. The mineral metabolism of the milch cow. Urbana, 1922. 30 p. (Ohio Agricultural Experiment Station. Bulletin 363)

18. Geldreich, J. F. et al. Type distribution of coliform bacteria in feces of warm blooded animals. Journal of Water Pollution Control Federation 34:295-301. 1962.

19. Gerretson, F. C. and H. deHoop. Nitrogen losses during nitrification in solutions and in acid sandy soils. Canadian Journal of Microbiology 3:359-380. 1957.

20. Glerium, A., G. Klomp and H. R. Poelma. The separation of solid and liquid parts of pig slurry. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers. Pub. Proc. 271. St. Joseph, Mich. p. 293-296. 1971.

21. Goodrich, P. R. and E. J. Monke. Movement of pollutant phosphorus in saturated soils. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 325-328. 1971.

22. Goring, C. A. I. and W. V. Bartholomew. Adsorption of mononucleotides, nucleic acids and nucleoproteins by clay. Soil Science 74:149-157. 1952.

23. Griffiths, A. B. A treatise on manures. 3rd ed. New York, D. Van Nostrand Co., 1922. 310 p.

24. Harmsen, G. W. and G. J. Kolenbrander. Soil inorganic nitrogen. Soil nitrogen, ed. W. V. Bartholomew and F. E. Clark. American Society of Agronomy Monograph #10, Madison. p. 104-172. 1965.

25. Holt, R. F., D. R. Timmons and J. J. Latterell. Accumulation of phosphates in water. Journal of Agricultural and Food Chemistry 18:781-784. 1968.

26. Hsu, P. H. and D. A. Rennie. Reactions of phosphate in aluminum systems. I. Adsorption of phosphate by X-ray amorphous aluminum hydroxide. Canadian Journal of Soil Science 42:197-209. 1962.

27. Jackson, M. L. Soil chemical analysis. Englewood Cliffs, Prentice-Hall. 1958. 310 p.

28. Jansson, S. L. Tracer studies on nitrogen transformations in soil with special attention to mineralization--immobilization relationships. Kungl. Lantbrukshogskilans annales 24:101-361. 1958.

29. Johnson, W. R. et al. Nitrogen and phosphorus in tile drainage effluents. Soil Science Society of America 29:287-289. 1965.

30. Koelliker, J. K. and J. R. Miner. Use of soil to treat anaerobic lagoon effluent renovation as a function of depth and application rate. Transactions of American Society of Agricultural Engineers 13:496-499. 1970.

31. Koelliker, J. K. et al. Treatment of livestock lagoon effluent by soil filtration. Livestock Waste Management and Pollution

Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 329-333. 1971.

32. Loeher, R. C. Pollution implications of animal wastes. A forward oriented review. U. S. Dept. Interior, Federal Water Pollution Control Admin., Robert S. Kerr. Water Research Center. Ada, Okla. 1968. 116 p.

33. Manges, H. L. et al. Land disposal of cattle feedlot wastes. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 62-65. 1971.

34. Mathers, A. C. and B. A. Stewart. Crop production and soil analysis as affected by application of cattle feedlot waste. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 229-231. 1971.

35. McCalla, T. M., L. R. Fredrick and G. L. Palmer. Manure decomposition and fate of breakdown products in soil. Agricultural practices and water quality, ed. T. L. Willrich and G. E. Smith. Iowa State University Press, Ames, Iowa. p. 121-136. 1970.

36. McCaskey, T. A., G. H. Rollins and J. A. Little. Water quality of runoff from grassland applied with liquid, semi-liquid, and dry dairy waste. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 239-242. 1971.

37. Miner, J. R. and T. L. Willrich. Livestock operations and field spread manure as source of pollutants. Agricultural practices and water quality, ed. T. L. Willrich and G. E. Smith. Iowa State University Press, Ames, Iowa. p. 100-115. 1970.

38. Morrison, F. B. Feeds and feeding, abridged. 9th ed. Clinton, Iowa, Morrison. 1961. 696 p.

39. Muehling, A. J. Swine housing and waste management. Dept. of Agricultural Engineering AEng-873. University of Illinois at Urbana-Champaign. 1969. 91 p.

40. Magelschmidt, G. and H. L. Nixon. Formation of apatite from superphosphate in the soil. Nature 154:428-429. 1944.

41. Nelson, C. E. Methods of applying ammonium nitrate fertilizer on field corn and a study of the movement of NH_4^+ and NO_3^- nitrogen in soil under irrigation. Agronomy Journal 45:154-157. 1953.

42. Nelson, D. W. and M. J. M. Romkens. Transport of phosphorus in surface runoff. Relationship of agriculture to soil and water pollution. Conference on Agricultural Waste Management, Cornell University. p. 215-225. 1970.

43. Pratt, P. F. and F. L. Blair. Cation-exchange properties of some acid soils of California. Hilgardia 33:689-706. 1962.

44. Raney, W. A. The dominate role of nitrogen in leaching losses from soils in humid regions. Agronomy Journal 52:563-566. 1960.

45. Reddell, D. L. et al. Disposal of beef manure by deep plowing. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 235-238. 1971.

46. Robbins, W. D. et al. Quality of effluent from farm animal production sites. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 166-169. 1971.

47. Roberts, S. et al. Methods of soil analysis used in the soil testing laboratory at Oregon State University. Corvallis, 1971. 39 p. (Oregon. Agricultural Experiment Station. Special Report 321)

48. Robinson, J. B. D. The critical relationship between soil moisture content in the region of the wilting point and the mineralization of natural soil nitrogen. Journal of Agricultural Science 49:100-105. 1957.

49. Sauchelli, V. Phosphates in agriculture. New York, Reinhold. 1965. 277 p.

50. Sawyer, C. N. Some new aspects of phosphates in relation to lake fertilization. Sewage Indiana Wastes 24:768. 1952.

51. Sims, J. R. Nitrates--people, food, pollution, evolution change. Agricultural Nitrogen News 18:44-49. 1968.

52. Smith, S. M. and J. R. Miner. Stream pollution from feedlot runoff. Transactions of the 14th Annual Conference on Sanitary Engineering Bulletin. University of Kansas Pub. Lawrence, Kansas. p. 115-124. 1970.

53. Sohn, J. B. and M. Peech. Retention and fixation of ammonia by soils. Soil Science 85:1-9. 1958.

54. Staley, L. M., N. R. Bulley and T. A. Windt. Pumping characteristics, biological and chemical properties of dairy manure slurries. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 142-145. 1971.

55. Stewart, B. A. et al. Nitrate and other water pollutants under fields and feedlots. Environmental Science and Technology 1:736-739. 1967.

56. Swanson, N. P. et al. Transport of pollutants from sloping cattle feedlots as affected by rainfall intensity, duration and reoccurrence. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 51-55. 1971.

57. Sylvester, R. O. Nutrient content of drainage water from forested, urban and agricultural areas. Algae and Metropolitan Wastes. U. S. Public Health Service, SECTR W61-3:80. 1961.

58. Thorne, D. W. and H. B. Peterson. Irrigated soils. 2nd ed. New York, Blakiston. 1954. 392 p.

59. Turnbull, J. E., F. R. Hore and M. Feldman. A land recycling liquid manure system for a large scale confinement operation in a cold climate. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 39-43. 1971.

60. Turner, D. O. and D. E. Procter. A farm scale dairy waste disposal system. Livestock Waste Management and Pollution Abatement, American Society of Agricultural Engineers Pub. Proc. 271. St. Joseph, Mich. p. 85-88. 1971.

61. Waksman, S. A. Soil microbiology. New York, Wiley and Sons. 1952. 356 p.

62. Watts, D. P. Willamette Valley soils hydraulic conductivity studies. Dept. of Agricultural Engineering, Oregon State University, Corvallis, Oregon. 1965.

63. Willrich, W. L. and G. E. Smith (eds.). Agricultural practices and water quality. Iowa State University Press, Ames, Iowa. 1970.

APPENDIX

APPENDIX A

Established Series
Rev. GEO-AON
3/70

AMITY SERIES

The Amity series is a member of the fine-silty, mixed, mesic family of Argiaquic Xeric Argialbolls. Amity soils have very dark grayish brown silt loam Ap horizons, light gray silt loam A2 horizons, silty clay loam Bt horizons that are grayish brown in the upper part, light olive brown in the lower part and are mottled throughout, and mottled olive brown silty clay loam C horizons.

Typifying Pedon: Amity silt loam - cultivated
(Colors are for moist soil unless otherwise stated.)

Ap 0-7" -- Very dark grayish brown (10YR 3/2) silt loam, grayish brown (10YR 5/2) dry; moderate fine subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; many roots; many irregular pores; medium acid (pH 5.8); clear smooth boundary. (5 to 8 inches thick)

A1 7-16" -- Very dark grayish brown (10YR 3/2) silt loam, grayish brown (10YR 5/2) dry; moderate medium subangular blocky structure; hard, slightly sticky, slightly plastic; many roots; common irregular pores and few very fine tubular pores; medium acid (pH 5.8); clear smooth boundary. (5 to 10 inches thick)

A2 16-22" -- Dark gray (10YR 4/1) silt loam light gray (5Y 7/1) dry; common fine faint brown and black mottles; weak medium subangular blocky structure; soft, very friable, slightly sticky, slightly plastic; common roots; many irregular pores; common medium brown and black concretions; medium acid (pH 5.8); clear wavy boundary. (4 to 12 inches thick)

B21t 22-28" -- Grayish brown (10YR 5/2) silty clay loam, pale brown (10YR 6/3) dry; common fine faint brown and black mottles; weak medium prismatic structure that parts to moderate very coarse subangular blocky structure; hard, friable, sticky, plastic; few roots; common very fine tubular pores; clean silt and sand grains on faces of prisms; common moderately thick clay films in pores and on all vertical ped faces; medium acid (pH 6.0); gradual wavy boundary. (4 to 9 inches thick)

B22t 28-35'' -- Light olive brown (2.5Y 5/4) silty clay loam, very pale brown (10YR 7/4) dry; common fine distinct reddish brown, gray, and black mottles; weak coarse prismatic structure that parts to moderate coarse subangular blocky structure; very hard, firm, sticky, plastic; few fine roots; common very fine tubular pores; common moderately thick clay films in pores and on vertical ped faces; slightly acid (pH 6.2); diffuse boundary. (5 to 14 inches thick)

C 35-72'' -- Olive brown (2.5Y 4/4) silty clay loam, very pale brown (10YR 7/4) dry; common fine faint mottles; massive; hard, friable, slightly sticky, slightly plastic; common very fine tubular pores; thick clay films in some pores; slightly acid (pH 6.4).

Type Location: Linn County, Oregon; 5,000 feet east from Grand Prairie School, 50 feet west of north and south gravel road, SE 1/4 SE 1/4 NW 1/4 sec. 15, T. 11 S., R. 3 W.

Range in Characteristics: The mean annual soil temperature ranges from 53° to 55° F. The thickness of the solum ranges from 30 to 50 inches. Depth to bedrock is more than 60 inches. A perched water table is at less than 24 inches depth during winter. Total thickness of the Ap and A1 horizons ranges from 10 to 18 inches. These horizons have values of 2 or 3 moist and 4 or 5 dry and chromas of 2 or 3. The A2 horizon has values of 3 to 5 moist and 6 or 7 dry and chromas of 0 to 2. It contains faint to distinct mottles. The B2t horizon has hues of 10YR or 2.5Y, values of 4 or 5 moist and 6 or 7 dry, and chromas of 2 through 4. It has weak to moderate structure in the upper part and in the lower part has some brittleness like that of fragipans. It is heavy silt loam or silty loam averaging 27 to 35 percent clay.

Competing Series and Their Differentiae: These are the Holcomb, Santiam, and Woodburn series. Holcomb soils have an abrupt textural change in the upper part of the sola and silty clay Bt horizons. Santiam soils have ochric epipedons, lack A2 horizons, and have Bt horizons that average more than 35 percent clay. Woodburn soils lack an A2 (albic) horizon above the Bt horizon.

Setting: The Amity soils are on nearly level, broad terraces at elevations of 150 to 400 feet. They formed in homogeneous, light brown, faintly stratified silty alluvium. Summers are warm and dry and winters are cool and moist. Mean annual precipitation is 40 to 45 inches. Average January temperature is 39°F., average July temperature is 67°F., and mean annual temperature ranges from 50° to 54° F. Average frost-free season ranges from 165 to 210 days.

Principal Associated Soils: These are the Holcomb and Woodburn soils listed as competing series, and the Aloha, Concord, Dayton, and Willamette soils. Aloha soils lack A2 and Bt horizons. Concord and Dayton soils have fine-textured Bt horizons and an abrupt textural change. Willamette soils are well drained and lack A2 horizons and mottles within 40 inches of the surface.

Drainage and Permeability: Somewhat poorly drained. Runoff is slow. Permeability of the B horizon is moderately slow.

Use and Vegetation: Most of the soil is cropland or in pasture. Small grain, grass seed, and hay are the main crops. Some cannery crops are grown where the soil is artificially drained. A small amount remains in native vegetation of annual and perennial grasses, wild blackberries, wild rose, and widely spaced oak trees.

Distribution and Extent: Amity soils are throughout the Willamette Valley of western Oregon. They are moderately extensive.

Series Established: Yamhill County, Oregon, 1917.

Remarks: The Amity soils were formerly classified as Gray-Brown Podzolic soils intergrading to Low-Humic Gley soils.

National Cooperative Soil Survey
U. S. A.