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Animal Waste Management Facilities And Systems

JOHN I. SEWELL*

Tendencies toward larger animal production units, greater animal concentrations, needs to reduce labor requirements, and concern for environmental quality have led to much interest in the development of animal waste management systems. Since 1967, animal waste management research related to water quality, liquid dairy manure systems, dairy manure slurry irrigation, slatted floor swine systems, slatted floor beef finishing systems, liquid poultry manure management systems, and waste applications on crop land has been conducted at the following locations: the Dairy Experiment Station at Lewisburg; the University of Tennessee Alcoa Farm, Dairy, and Poultry Farm at Knoxville; the Middle Tennessee Experiment Station at Spring Hill; the University of Tennessee Cooperative Animal Research Laboratory at Oak Ridge; and the West Tennessee Experiment Station at Jackson.

The work summarized in this bulletin has been partly reported as indicated in the references. All superintendents of experiment stations where work was conducted have contributed to the work. Several research scientists and graduate students as acknowledged in the various sections have conducted much of this work under Tennessee Agricultural Experiment Station Projects H-277 and H-367R, "Farm Waste Disposal." The dairy manure slurry irrigation studies were supported in part by the University of Tennessee Water Resources Research Center Project A-021-TN, "The Effects on Runoff, Groundwater, and Land of Irrigating with Cattle Manure Slurries." All work done after July, 1972 contributed to Southern Regional Research Project S-89, "Animal Waste Treatment and Recycling Systems."

*Research Leader of animal waste management studies, University of Tennessee, Knoxville, Tennessee.

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Waste Management For Slatted Floor Beef Finishing Systems

JOHN I. SEWELL, J. B. McLAREN, G. D. MILLER, J. E. MARTIN, and J. N. ODOM*

A slatted floor beef finishing facility was completed in 1971 at The University of Tennessee Aluminum Company of America[2] (ALCOA) Farm. An existing barn with a concrete slab floor was remodeled to include aluminum slat (Figure 1) and reinforced-concrete slat floors installed over manure collection pits in 14 pens. The concrete slab was left intact in six pens. The objectives of this study were to develop waste management criteria, characterize the liquid waste produced, and monitor cattle performance.

Liquid manure was removed from the pits by vacuum tank-spreaders and applied to crop or pasture land. A comparison was made between labor requirements for manure management from slatted floor and concrete slab floor systems. Data were also collected on manure accumulation rates, manure agitation, and manure removal procedures.

Slatted Floor Pen and Pit Design

Two experimental designs of aluminum slats manufactured by Alcoa with top widths of 6.0 inches and approximate depths of 3.5 inches and 4.5 inches were used. The Alcoa slats weighed about 2.0 pounds per linear foot. The reinforced concrete slats had top widths of 4.5 inches and were 5.5 inches deep (Midwest Plan Service, p. 208, 1973). The slatted floor pens were 12.5 feet by 17.5 feet; and about 31 square feet of floor space per animal was allowed in this study. This compares with 43 square feet allowed per animal for cattle on the concrete slabs.

One-half of the 4.0-foot deep pits had flat floors, and one-half were built with floors sloping (2.5%) toward sumps located in the centers of the pits. Approximate construction cost in 1971 for 4-

*Professor and Associate Head, Department of Agricultural Engineering, Knoxville; Associate Professor, Department of Animal Science; former Graduate Assistant, Department of Agricultural Engineering; Manager, Blount and Alcoa Farms; and Superintendent, Main Station, Knoxville, respectively.

[2] This work was supported by the Aluminum Company of America and the Tennessee Agricultural Experiment Station.

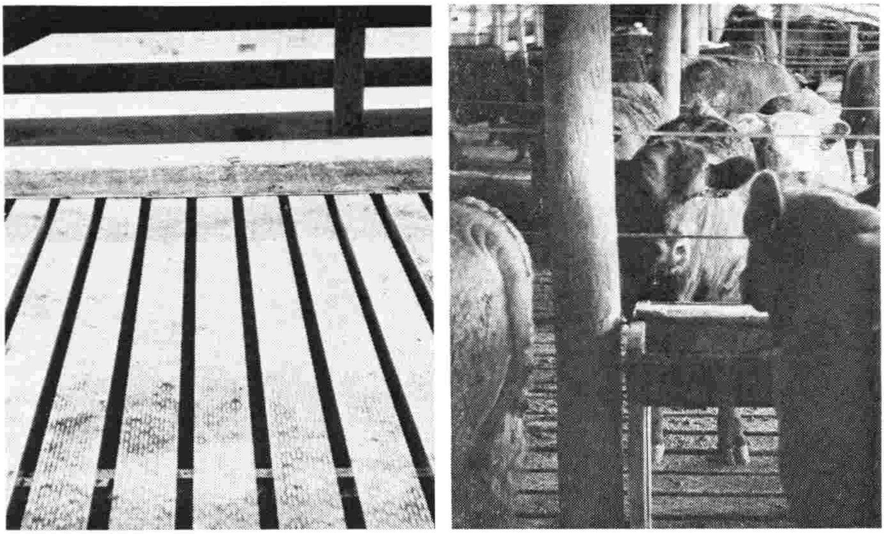

Figure 1. Experimental aluminum slatted floor (left) and cattle in aluminum slatted floor pen (right).

foot deep reinforced-concrete pits and concrete-slat floors was $3.50 per square feet of floor area. This did not include cost of the shelter or pens. The comparable cost of a concrete slab was about $1.00 per square foot. Construction details are given by Sewell and McLaren (1973).

Waste Management

Manure Characteristics and Accumulation Rates. Based on weekly determinations, liquid manure (including water added after pit emptying) accumulated at the rate of 0.73 cubic foot per animal per day for cattle averaging 700 pounds. A summary of chemical properties of the liquid beef waste as determined by Miller (1975) is given in Table 1.

Manure Removal from Pits. The pits were pumped at 4- to 6-month intervals. Immediately after each pit emptying, about 6 inches of water was placed in the pits. Effective agitation of solids before removal by vacuum-tank spreader was achieved by operating for 1 hour a 125-cubic-foot per minute air compressor equipped with a 1.25-inch pipe which was placed between the slats and into the pit contents. The pits with sloped floors allowed the manure to flow into the sumps as pumping neared completion resulting in more thorough removal of waste.

Effective waste removal by vacuum tank was not possible with-

Table 1. Mean chemical properties of liquid beef waste samples collected from pits under slatted floors

Test	Numbers	Concentration %	Concentration ppm
Kjeldahl N	8	0.38[c]	3,750
COD[a]	8	12.6	126,000
Phosphate	6	0.22	2,150
Dry matter, top[b]	24	7.1	71,000
Dry matter, bottom[b]	24	11.0	110,000
Dry matter, mean	48	9.1[c]	90,500

[a] Chemical oxygen demand.
[b] Near top or bottom of full pit.
[c] Dry matter was 4.15% Kjeldahl N.

out prior agitation. This agrees with Jedele and Andrew (1972) who found that liquid beef manure stored for 6 months required considerable agitation to transform the manure into a pumpable slurry.

Labor for Manure Removal. Labor required for manure removal (Table 2), using one spreader during the winter of 1971-1972, was similar for the slab and slat floors. However, the one-way haul distance (3.0 miles) for the liquid manure from the pits was more than twice that (1.3 miles) for manure from the slabs. (Because of odors associated with spreading the liquid manure from the pits, a more remote field area was used for spreading manure from the pits than from the slabs.)

Table 2. Labor required for removal of liquid manure from pits, hauling manure to fields, and spreading

Date	Floor type	Number of spreaders[a]	Haul distance[b]	Man hours per head per day
Winter, 1971-1972	Slab	1	2.1	0.012
Winter, 1971-1972	Slat	1	4.8	0.011
Spring, 1973	Slat	1	5.7	0.009
Fall, 1973	Slat	2	4.8	0.008
Spring, 1974	Slat	2	5.7	0.007

[a] Two men were required when one spreader tank was used; three men were required for two tanks.
[b] One way from barn to field, miles.

Road travel time of 15 minutes one way for liquid manure was a major factor in the high labor requirements. Using two spreader tanks rather than one, the average time required for loading the tank, travel to field, spreading on field, and return to pit was re-

duced from 1.87 to 1.40 man hours per load. For equal haul distances, the pit system required less labor, but more expensive equipment, for manure management than the slab system.

Cattle Performance

Cattle performance studies were reported by McLaren and Sewell (1973). Except during summer, cattle on aluminum slats, concrete slats, and concrete slabs performed similarly. Cattle on all slatted floors in summer had some swelling of knees. Cattle on concrete slabs had little. The swelling did not adversely affect performance. Few knee-swelling and other problems with cattle on feeding tests developed except in summer.

During summer, cattle on slatted floors ventilated with electric fans appeared more comfortable and performed better than cattle not allowed ventilation (Table 3). Floor types affected ($p<0.14$) average daily gain of both steers and bulls. Cattle in the ventilated slat pens gained an average of 0.11 and 0.23 pound per animal per day more than those in the unventilated slat and unventilated concrete slab pens, respectively. Feed conversion of steers in the ventilated slat pen equalled that of those in the unventilated slat pen and exceeded that in the unventilated slab pen. Bulls confined to ventilated slat floors exceeded those on unventilated slat and unventilated slab floors in feed conversion and rate of gain. This comparison supports the report of Ittner et al. (1956) in their studies of the effect of ventilation on cattle performance.

Table 3. Performance of cattle on slat and slab pens during 1974 summer test

	Treatment for 102-Day test					
	Unventilated slab pens		Unventilated slat pens		Ventilated slat pens	
	Bulls	Steers	Bulls	Steers	Bulls	Steers
Number	7	7	7	7	6	6
ADG[a]	2.51	2.55	2.60	2.69	2.78	2.73
Feed/Gain[b]	8.0	10.1	7.8	8.6	7.2	8.6

[a] Average daily gain, pounds per day.

[b] Feed efficiency, pounds of feed per pound of gain.

Observations

During the 3 years' operations, several observations were made:

1. Cattle on both types of slats were cleaner than those on slabs; however, no bedding was used on the slabs.
2. Some slipping and falling occurred on all slats and slabs.

3. Slab pens were scraped at least once, and usually twice, per week with the manure being stockpiled until weather conditions were suitable for field disposal. Careful management was required to prevent water runoff and seepage from the stack.
4. Objectionable odors were not detected outside the immediate vicinity of the barn except during agitation and emptying of the pits. After spreading liquid manure on the ground surface, objectionable odors were often present for up to 3 days.
5. The experimental aluminum slats incurred only minor mechanical damage during 3 years' use; however, during the fourth year, some slats showed signs of damage.
6. Slatted floors over collecting pits minimized manure drainage problems in the vicinity of the barn.

Conclusions

Slatted floor systems provided additional flexibility in scheduling waste removal operations to coincide with favorable weather, field conditions, timeliness of application to land, and labor availability. Labor requirement for waste removal and management was less for slatted floors than for slabs if the haul distance was equal. Liquid waste collected in the pits at the rate of 0.73 cubic foot per animal per day. Cattle on slats were cleaner than those on slabs.

Agitation in the pits was effectively achieved by injecting compressed air into the pit contents. Supplemental agitation of liquid waste was necessary before its removal by vacuum-tank spreader. Constructing pits with sloped floors and center sumps facilitated more thorough removal of the waste.

Mean values of Kjeldahl N, COD, phosphate, and dry matter for the liquid beef waste were 3,750; 126,000; 2,150; and 90,500 parts per million (ppm), respectively.

Problems associated with slatted floor systems are high facility investment, odors after spreading waste, and providing satisfactory environmental conditions for cattle during summer.

Liquid Manure Systems For Dairies

JOHN I. SEWELL, JOHN R. OWEN, and JOE W. HIGH*

Facilities

Manure was scraped, flushed, or augered into underground holding pits where it was stored until weather conditions, cropping systems, and labor schedules were such that the manure could be spread on fields. Such systems required concrete slabs or gutters for easy loading of the pit, a pit of concrete or some other durable material, equipment for agitating the manure in the pit, and equipment for pumping the liquid into a tank in which it could be hauled and spread on fields.

In 1967, liquid manure holding pits were constructed at the Dairy Experiment Station at Lewisburg and the Middle Tennessee Experiment Station at Spring Hill. The reinforced concrete pits with 10-inch-thick walls had inside dimensions of 20 x 40 x 10 feet deep. The top slabs were designed to support the weight of a tractor and loaded spreader tank. Columns to support the tops were constructed on 10-foot centers along the center lines of the floors of the pits.

The elevation of the top slab of the Dairy Experiment Station pit is such that little runoff from the slab flows into the pit openings. Each of the top slabs was provided with two manure drops and access and agitator-pump openings. Current pit design standards and requirements are available from the Tennessee Department of Public Health (1975).

The initial total cost for constructing the pits and floor slabs near the pits in 1967 was $6,800. On a storage volume basis, the cost was $0.85 per cubic foot or $0.113 per gallon. Sewell, Owen, and High (1970) prepared a detailed report of the results.

Field Tests at the Dairy Experiment Station

Before pit construction, the manure from the dairy milking 140-145 cows was scraped daily from a loose housing system with holding pens and lots where it was stored temporarily before field

*Professor and Associate Head, Department of Agricultural Engineering, Knoxville; Superintendent, Dairy Experiment Station, Lewisburg; and Superintendent, Middle Tennessee Experiment Station, Spring Hill, respectively.

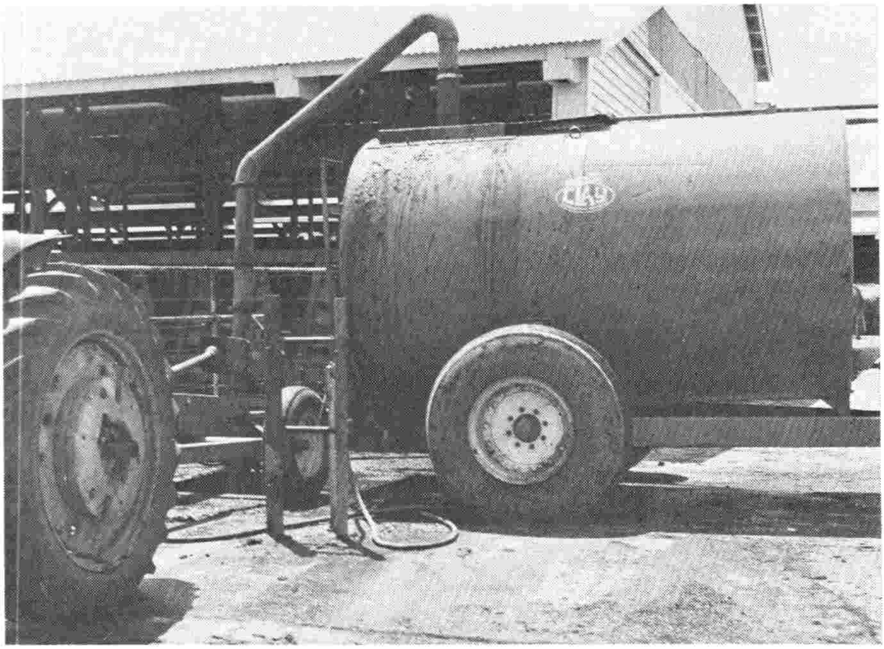

Figure 2. Emptying liquid dairy manure from a pit.

spreading. In comparing the labor requirements for the loose housing system with the liquid manure system and new free-stall housing for the same size herd, average man-minutes per day decreased from 105 to 58.

An important advantage of the liquid manure system was evident during winter months when excess rain frequently made handling "solid" waste material difficult with conventional loading equipment. Some liquid in wastes facilitates operation of the liquid manure system.

During two winter seasons, the manure from 120 cows under confined conditions was scraped into the pit, and the average time between pit emptyings was 28 days. During two spring and summer seasons, the manure from 150 cows under partial confinement was scraped into the pit. Under these conditions, the average time between pit emptyings (Figure 2) was 36 days.

The pit was agitated once or twice between emptyings, and it was always agitated immediately before emptying. The amount of waste from feeding green chop or hay and the moisture content of the manure being scraped into the pit affected the required fre-

quency of agitation. During the summer, scraping the lots early in the morning before the manure had dried reduced agitation problems.

About 20 inches of dairy barn wash water were added to the 20- x 40-foot liquid manure pit immediately after each pumping. Thus, 10,000 gallons were added. Including the 20 inches of water added to facilitate agitation, the loading rates per cow per day were 1.26 and 2.00 cubic feet under partial confinement and confinement, respectively.

Field Tests at Middle Tennessee Experiment Station

During a year's test, the liquid manure pit received the manure from 80 to 100 Holstein cows which remained in the lot for 18 to 20 hours per day. About 4 gallons of water per cow per day were added to the pit in lot-cleaning operations. During agitation before emptying the pit, 2,000 to 15,000 gallons of water were often added to the pit. The average period between emptying the pit was 36 days. The average rate of manure plus water accumulation was 2.20 cubic feet per cow per day.

About 7 hours was usually required to empty the pit with two 1,500-gallon spreader tanks. When little water was added between emptyings, agitating the pit contents was sometimes difficult. The pump has occasionally been clogged with twine, hay, and wood chips.

Between 1968 and 1972, the dry-matter content of the liquid manure varied between 9% and 16%. Most samples contained about 11% dry matter, 9.4% volatile solids, and 1.6% ash. The samples averaged 11% chemical oxidation demand, 100 parts per million (ppm) nitrate-nitrogen, and 1,200 ppm orthophosphate.

Few odors were experienced during normal operation of the liquid manure system. However, during agitation and emptying of the pit and for a few days after the manure was spread on fields, objectionable odors have resulted.

Potential Hazards of Liquid Manure Systems

Many gases are known to be formed in liquid manure pits. The most dangerous are hydrogen sulfide, methane (highly flammable), and carbon dioxide. Explosions of methane gas have been reported, and high concentrations of hydrogen sulfide and/or carbon dioxide may overcome persons and animals, especially during pit agitation when trapped gases may be freed. Entering a manure pit is dangerous.

Laboratory Studies of Liquid Manure Pit Agitation

Distorted-model studies of liquid manure agitation in rectangular (twice as long as wide) and round pits were conducted to determine the effects of top-support columns, center baffles, and side baffles (Figure 3) on agitation efficiency. The modeling theory was outlined by Sewell (1971).

No difference was found between the model circular and rectangular pits in the quantity of slurry removable by pumping. Cover support columns did not significantly reduce the quantity of slurry removable. With the agitator located near the midpoint of the center baffle in the rectangular pit, the presence of the center baffle severely impaired agitation effectiveness. With the agitator near the end of the rectangular pit, adding a center baffle increased the quantity of slurry removable. Using two baffles along each side of the pit and no center baffle further improved agitation and solids removable. The combined use of side and center baffles in the tests eliminated the deposition of solids in the rectangular pit.

Field experience at the Dairy and Middle Tennessee Experiment Stations has substantiated the results of the model studies for the rectangular tank in that few agitation problems have been encountered with the pits having cover support columns.

Conclusion

Liquid manure pits for dairy herds offered advantages in that manure storage was available during periods when field areas were

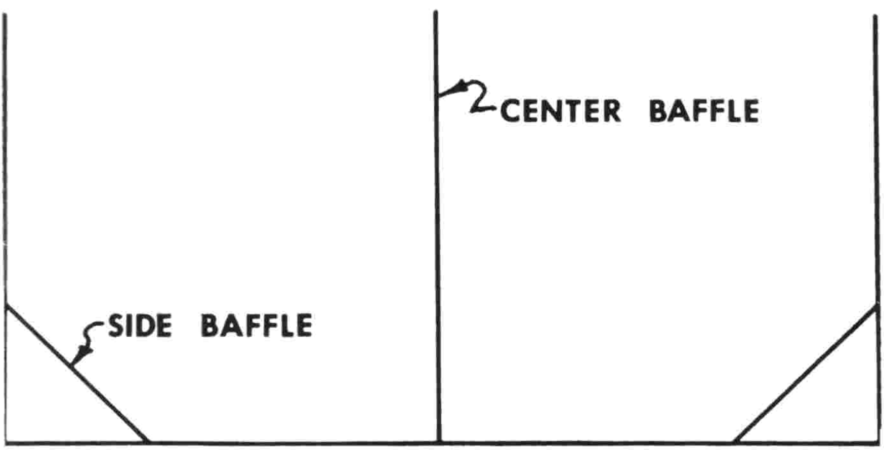

Figure 3. Cross section view of model rectangular manure pit with baffles.

not accessible, labor requirements were often decreased, and the scheduling of manure removal to better coincide with labor availability and field conditions was facilitated. With proper management, few agitation problems were encountered.

Primary disadvantages of the systems follow: land must be available on which to spread the waste before the pit becomes full; odor and fly problems can develop immediately after waste has been spread; and facility and equipment investments are high.

Liquid Swine Waste Management

JOHN I. SEWELL and H. W. LUCK*

Slatted-Floor Barn

A swine testing barn with 24 pens each 6 x 16 feet was put into operation at the West Tennessee Experiment Station in October, 1970. The barn was equipped with slatted floors and a liquid manure pit (Figure 4). The liquid manure from the collection pit is removed by a vacuum spreader tank equipped with two plows for placing the waste beneath the surface of crop land.

The pit varies from 3.5 feet deep in the center to 4.0 feet deep at each end giving a total storage capacity of 4,500 cubic feet. The pit walls are constructed of 8-inch concrete blocks with concrete-filled cores. The concrete floor of the pit slopes 1 inch in 10 feet toward each end where 6-foot deep sumps are located. The concrete slats are 8 feet long and 5 inches wide, and spaced 1 inch apart (Midwest Plan Service, p. 208, 1973). Waterers are on the slats at the opposite ends of the pens from the feeders. Each pen has an overhead spray nozzle used for cooling animals during periods of high temperatures.

Waste Management

Before pigs were put in the pens, an average of 16 inches of water was put into the pit. Additional water enters the pit from cleaning pens, leakage and spillage from waterers, and using sprinklers for cooling. The pits are emptied after each feeding cycle, about 100-150 days, unless leakage from waterers and sprinklers requires more frequent emptying.

During the October, 1970 through August, 1971 period, when the waterers and sprinklers leaked little, the liquid waste collected at 0.27 cubic feet per pig per day. During the summers of 1972 and 1973, when the sprinklers were heavily used and some waterers developed leaks, the waste accumulated at 0.55 and 0.64 cubic feet per pig per day, respectively. For 4 years of operation, the average

*Professor and Associate Head, Department of Agricultural Engineering, Knoxville, and Superintendent, West Tennessee Experiment Station, Jackson, respectively.

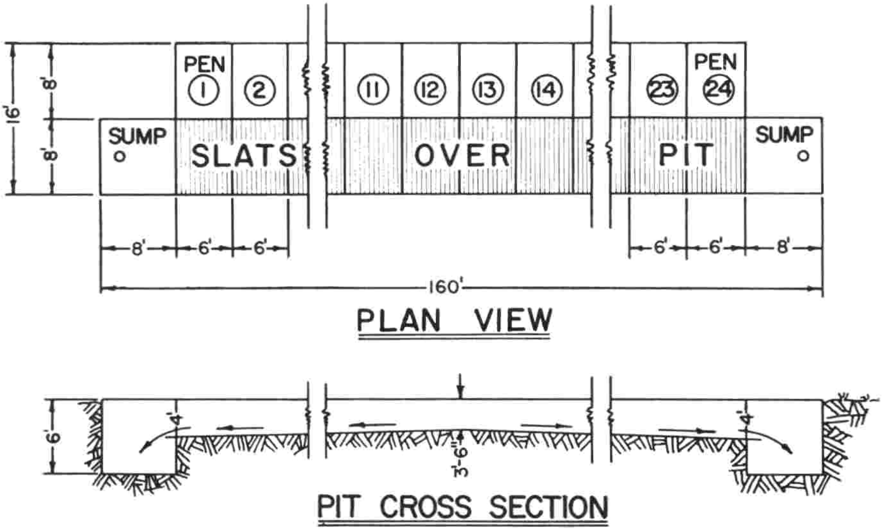

Figure 4. Schematic view of slatted floor swine facility with pit.

accumulation rate was 0.45 cubic foot per pig per day. These compare with daily liquid manure accumulations including wash water and dilution water of 0.27 cubic foot per 200-pound pig as reported by the Tennessee Department of Public Health (1973) and the Midwest Plan Service (p. 195, 1973).

A commercially-available 1,500-gallon liquid manure transport tank with a combination vacuum-pressure pump was used to remove the waste from the pit sumps. The tank (Figure 5) is equipped with two plows which apply waste beneath the soil. The waste flows from the pit into the sumps (Figure 4), usually leaving some settled solids on the pit floor.

With the plows about 1 foot into the soil and the pressure pump operating, the liquid waste was forced into the soil and covered. The soil had previously been plowed. About 1 gallon of waste per plow per foot of travel was applied. Details of facility and equipment operation were reported by Sewell and Overton (1973).

Odors from nearby fields where manure was injected were mild, if noticeable, on the day of application; and unless the weather was damp or humid, they were not detected the next day. The silt loam soils readily absorbed the liquid waste. The soils have no stones which probably accounted for the few mechanical problems with the equipment.

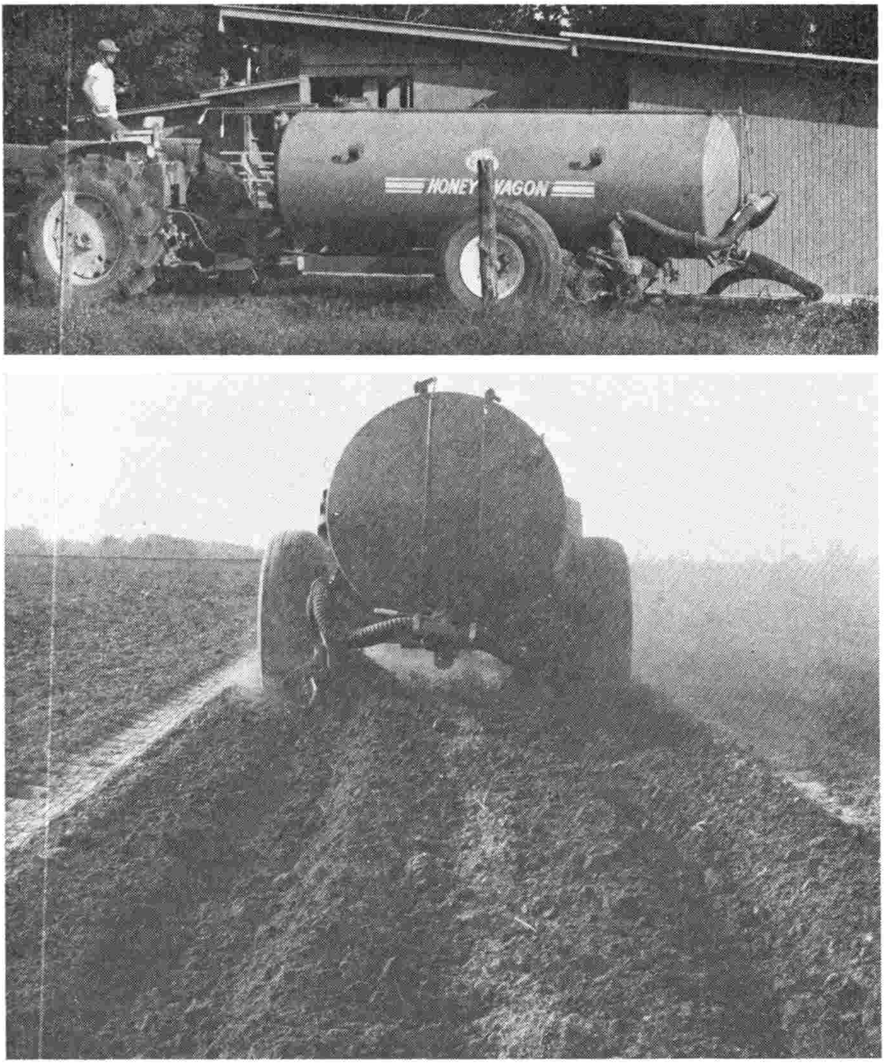

Figure 5. Vacuum tank removing liquid swine waste from sump (above) and applying waste beneath soil (below).

The average depths of the settled solids on the pit floor varied with time (Figure 6). During the first few months of operation, solids accumulated rapidly possibly because anaerobic bacteria had not yet become active. During the winters of 1971-1972 and 1972-1973, average depths of settled solids accumulated to approximately

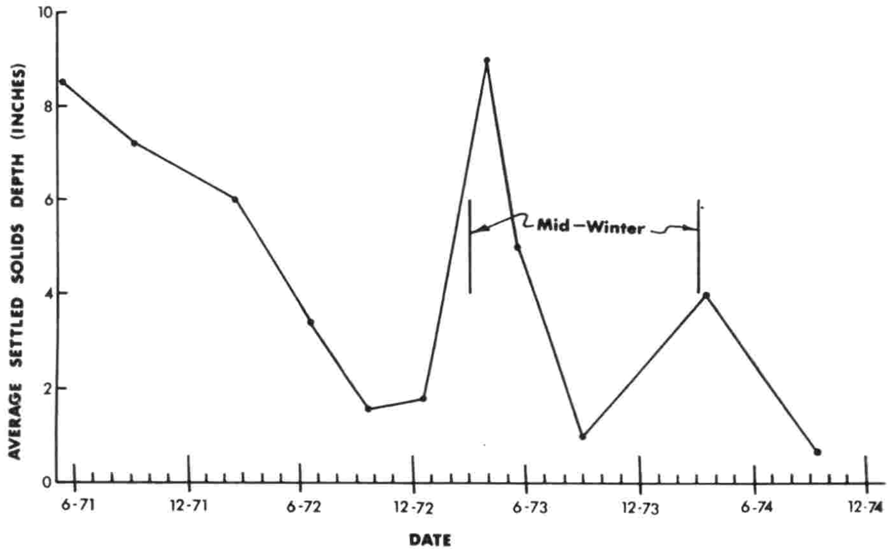

Figure 6. Variation of average depths of settled swine waste solids on pit floor.

9 inches; and during the mild winter of 1973-1974, accumulations reached only 4 inches. During the summer months, presumably when bacterial decomposition rates had increased because of higher temperatures, settled solids not previously removable by pumping from the sumps decreased markedly due primarily to better solids liquefaction. Solids accmuluations have not caused problems in tank loading or system operation even though the pit contents have not been agitated at any time.

Waste Characteristics

Chemical analyses of the liquid waste are given in Table 4. The low nitrogen concentrations were expected since denitrification occurs rapidly under anaerobic conditions. Samples from the bottom

Table 4. Chemical properties of liquid swine waste samples collected from pit underneath slatted floors

	Means of four replications, ppm	
Position in pit	Nitrate nitrogen[1]	Orthophosphate[2]
Top	9	280
Middle	9	260
Bottom	17	2,100

[1] As nitrogen. [2] 33% phosphorus.

of the pit contained much more nitrate nitrogen and orthophosphate than samples from the top of the pit. Bottom samples had a chemical oxygen demand of 80,000 parts per million (ppm) or 8%.

Conclusion

Liquid waste from a slatted-floor swine barn was removed by vacuum spreader tank and applied beneath the soil surface of crop lands. Few mechanical problems have been associated with waste removal or application to soil. Agitation of pit contents was not necessary.

During periods when swine-cooling sprinklers were not in use, the waste collected at 0.27 cubic foot per pig per day. Soon after the system was put into operation, the depth of settled solids on the pit floor averaged 8 inches; and 18 months later, the average depth had decreased to 2 inches. During 3 years' operations, the settled solids tended to accumulate from 4 to 8 inches depth in winter and then decline to about 2 inches depth in summer.

Liquid Poultry Waste

JOHN I. SEWELL*

In 1973, the dry-matter and viscosity characteristics of poultry manure which are closely related to slurry pumping characteristics were evaluated at The University of Tennessee Poultry Farm. The three caged layer houses studied were equipped with shallow pits under cages and a dragboard system for conveying the liquid manure from beneath the cages to liquid manure pits outside the houses.

Waste samples were collected from pits next to the houses. Before sample collection, the slurry was agitated and mixed. This was done by flushing the pit contents, as removed by a commercially-available liquid manure tank, back into each pit. Sample dry-matter contents on wet basis (oven-dry matter weight divided by weight of slurry) and viscosity (MacMichael viscosimeter) determinations were made according to accepted laboratory procedures.

During 15 days of sampling in the spring season, dry matter varied from 1.0 to 16.6% and viscosity varied from 0.99 to 940 centipoises. For comparison, the dry-matter content of fresh, un-

*Professor and Associate Head, Department of Agricultural Engineering, Knoxville.

diluted poultry feces is usually about 28% ; the viscosity of water at 20°C. is 1.00 centipoise. A semi-logarithmic summary plot of dry matter on viscosity is presented in Figure 7.

The sample viscosity increased markedly with dry-matter concentrations exceeding 10%. At dry-matter levels exceeding 10%, difficulties in vacuum loading a slurry tank and in pumping with a centrifugal sewer pump were experienced. Accumulations of feathers and other extraneous material also caused pumping problems.

The wide range in dry-matter contents of the slurry resulted from varying dilutions by wash water, spillage, leaking waterers, rainfall, and relative humidity. Adequately diluting the slurry was found to greatly facilitate pumping. However, the dilution water must also be hauled and spread on land; thus, total hauling costs are correspondingly increased.

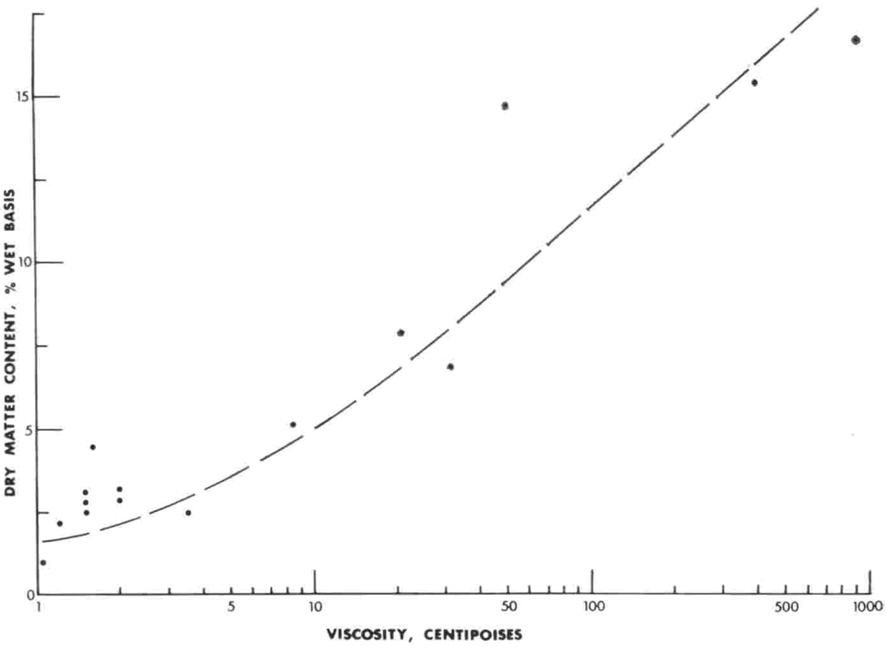

Figure 7. Effects of dry matter content on slurry viscosity of liquid poultry manure.

Sprinkler Irrigation of Dairy Manure Slurry

JOHN I. SEWELL, J. C. BARKER, CLYDE R. HOLMES, and J. N. ODOM*

Recent dairy trends include larger herds, more confinement, and the use of concrete outdoor lots. During rainfall, lot runoff usually contains concentrations of animal waste at levels which can cause water quality problems. An experimental manure slurry irrigation system was established at the University of Tennessee Main Station Dairy Farm milking 125 cows to study the collection of lot runoff and its disposal on land.

Facilities and Equipment

Figure 8 gives a layout of the dairy herd facilities served by the slurry irrigation system which was put into operation in October, 1970. The runoff from approximately 1 acre of lot and roof area is collected into drains and flows by gravity into the slurry storage tank. A chute is used to direct the manure from the cow and storage barn into the slurry tank. An irrigation pump at the tank carries the slurry through portable irrigation pipe and applies it to land through a large sprinkler.

Two flush pits were installed in the main lot, and one was installed at the hay and resting barn. Manure is introduced into the pits through a chute or by scraping. The irrigation pump discharge is valved so that the discharge can be directed into any of the flush pits (Figure 9) or directly to the field. The manure slurry is recirculated through a 3-inch steel pipeline; it then flushes the manure into a 15-inch concrete pipeline leading to the storage tank. The 15-inch pipeline from the flush pits in the main lot was installed at a minimum grade of 2.0%. At one point, the pipe grade decreases from about 4% to about 2.5%. Here solid particles have settled in the pipeline as the flow velocity decreased. Otherwise, pipeline sedimentation has not occurred. Slurry is frequently irri-

*Professor and Associate Head, Department of Agricultural Engineering, Knoxville; Former Graduate Assistant, Department of Agricultural Engineering; Manager, Cherokee Dairy; and Superintendent, Main Station, Knoxville, respectively.

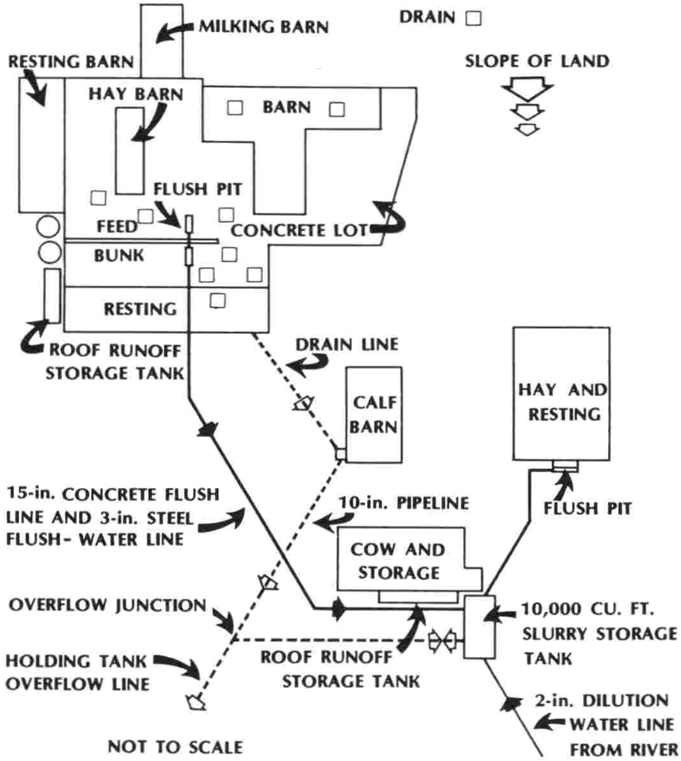

Figure 8. Layout of part of the University of Tennessee Knoxville Dairy farm facilities.

gated and replaced by water from lot runoff or two large roof runoff storage tanks. During periods of low rainfall, additional water is pumped into the slurry tank.

The inside dimensions of the slurry storage tank are 20- by 50-feet by 10-feet deep. Construction is of reinforced concrete with 10-inch walls and a prestressed concrete top designed to withstand 150 pounds per square foot live load for a heavy farm tractor.

The storage tank has capacity for 2.5 inches of runoff from the lots. This capacity will be available only if the tank is empty at the time of the rainfall. Irrigation pumping should be managed so that the storage tank will not be more than half full at the beginning of a rainfall period. Thus, the holding tank can accommodate at least 1.25 inches of lot runoff before it fills. During a 9-month period, the holding tank overflowed twice.

The commercially-available pumping system consists of a 15-horsepower (hp) chopper-agitator unit and a 25-hp open-impeller centrifugal pump. The sprinkler is equipped with a ⅞-inch di-

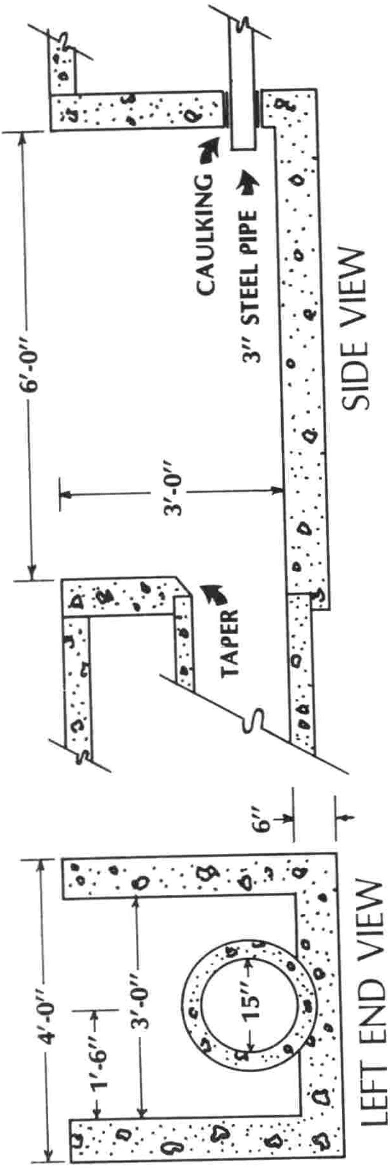

Figure 9. Schematic view of manure flush pits.

ameter rubber nozzle. All materials, equipment, and labor cost $18,000 in 1970. Costs for portable aluminum pipe and liquid manure agitation equipment were not included. A detailed report of the system design has been prepared by Sewell (1973).

System Operations

From 1970 through 1973, much of the manure and wastewater

from the herd was delivered into the storage tank. During the summer seasons, lot runoff has sometimes been insufficient to adequately dilute the slurry, and additional water was necessary. Sediment deposits have collected on the tank floor. These conditions require supplemental agitation and occasional solids removal by a conventional liquid manure agitator-pump and spreader tank. The removal of 3 to 4 feet of solids from the tank has been necessary about three times per year.

The tank should be partly pumped about twice each week. During periods of rainfall, the tank has been pumped more often to allow storage capacity for future lot runoff. Periods of wet weather require careful system management to avoid surface runoff of slurry applied to wet fields. For proper system performance, the level of the tank should be maintained sufficiently low to provide storage capacity for additional lot runoff to prevent tank overflow.

Except under wet soil conditions, the sprinkler was operated about 3 hours at each location. The average application rate was about 0.5 inch per hour; therefore, 1.5 inches of slurry was applied during one irrigation. To minimize surface runoff, the sprinkler covering about 1 acre per setting. (Figure 10) should be moved to a new location before the next irrigation.

Masses of dry hay and bedding have infrequently clogged the entrances of the flush pit return lines. Manure having high mois-

Figure 10. Manure slurry irrigation sprinkler covering about one acre each setting.

ture content and little hay rapidly enters the flush pit return lines.

Odors have not been objectionable except during agitation and pumping. These odors may often be detected down-wind from the sprinkler and near the storage tank. Odors appear to be more noticeable when slurry is applied on humid days than on clear days.

System Characteristics

Viscosity determinations were made with a MacMichael viscosimeter and certified wires. Temperatures were standardized at 25°C for all determinations.

Pump discharge at pressures varying between 53 and 57 pounds per square inch (psi) decreased with increasing viscosity and dry-matter content of slurry. The effects of the viscosity in centipoises (V) and dry matter in percent (DM) on pump discharge (Figure 11) in gallons per minute (gpm) (Q) follow.

$$Q = 214.0 - 1.579V \text{ and}$$

$$Q = 227.2 - 1.538\,DM.$$

The mean viscosity of the manure slurry also increased as the dry-matter content increased according to:

$$V = 2.091 + 1.998\,(DM)^2.$$

Increasing the dry matter up to about 4% caused no serious decreases in slurry discharge rates which averaged about 190 gpm. At 5.56% dry matter, the irrigation system performed well.

Effects of Manure Slurry Irrigation on Water Quality

A test area with two 55-foot groundwater observation wells was established. Barker and Sewell (1973) evaluated groundwater quality between March, 1971 and March, 1973. During this period, an average of about 5.5 tons dry matter per acre per month was applied as slurry. The slurry contained an average of 3.9% dry matter, and the average application rate was 1.3 inches slurry per month.

Published reports show the nitrogen (N) content of oven dry cow manure which is free of bedding to vary between 2.4% (Willrich and Smith, p. 242, 1970) and 3.9% (Graber, 1974). N losses through volatilization and anaerobic decomposition while the waste was temporarily in the storage tank are estimated to be about 30%. Since the system received bedding, sawdust, and waste hay, the N content of the slurry solids may have been near 50% of the value for fresh manure.

Assuming that fresh manure solids contain 3.0% N and taking

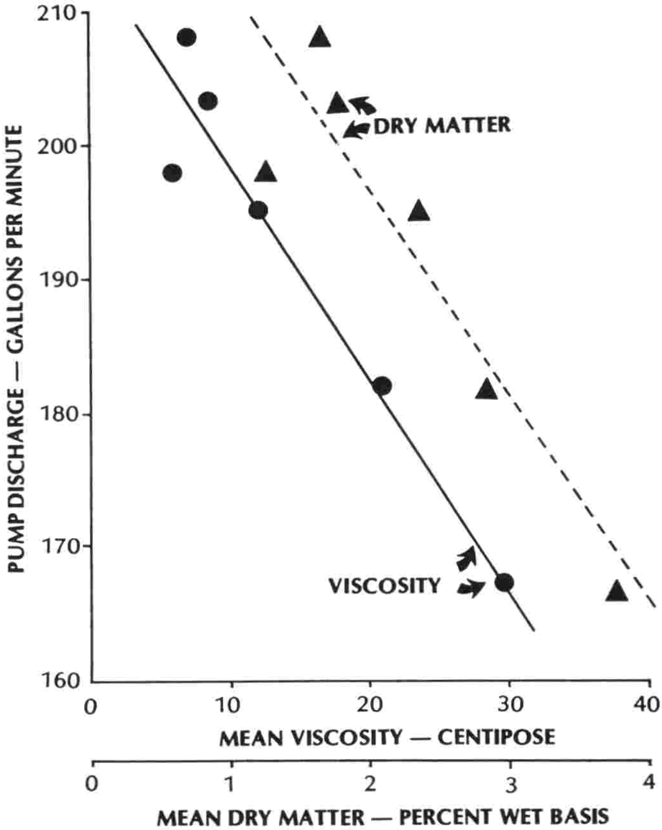

Figure 11. Effects of mean viscosity and dry matter on pump discharge.

into account losses and the bedding added, 1,400 pounds of N per acre per year were applied during the 1971-1973 period. However, probably no more than 50% of the N applied as manure slurry is released during the year in which the manure is applied. Considering all of the above factors, the rate at which N was applied still exceeds even the high rate of N fertilization (400 pounds maximum per acre per year) recommended for coastal bermudagrass hay.

The 4-acre test area having slopes which varied from 20% to almost flat is mostly fine-textured Cumberland clay loam with some cobbles in the lower strata. The shallow groundwater table is believed to be bounded underneath by a limestone stratum. The permeability of the surface soil is moderate to moderately rapid with an approximate rate of 2.0 inches per hour. The area was maintained in good pasture except during summers when it was seeded to a sudan-sorghum hybrid. The average annual rainfall is 50 inches per year.

The well (Table 5) on the downslope side of the test area (GW-2) contained water for continuous sampling; but the well on the upslope side (GW-3) yielded samples intermittently. The average depths from ground surface to water table, when samples were available, was 50 feet. Grab samples (Table 5) of surface runoff from three locations on the test area (SR-1, -2, and -3) were collected, and the physical properties of the manure slurry were analyzed. A summary of all analyses performed by Barker (1973) through March, 1973 is presented in Table 5.

Table 5. Median physical, chemical, and bacteriological properties of dairy manure slurry, shallow groundwater, and surface runoff through March 1973

	Slurry	GW-2[1]	GW-3[2]	SR-1[3]	SR-2[3]	SR-3[3]
Total solids, ppm	39,100	565	—	348	656	811
Dissolved solids, ppm	12,800	367	81	214	378	426
Suspended solids, ppm	26,300	198	—	134	278	385
Volatile solids, ppm	32,600	322	—	231	344	613
Ash, ppm	6,500	243	—	117	312	198
Total coliform[4]	—	375	15	39,000	43,000	60,000
Fecal coliform[4]	—	130	1	12,000	9,200	28,500
5-day BOD, ppm	—	2.3	1.2	19.2	26.5	35.0
NO_3-N, ppm	26	1.9	0.1	1.8	3.0	2.2
Orthophosphate, ppm	390	0.1	0.1	3.2	4.6	16.7
Chloride, ppm	—	56.2	2.5	33.8	47.5	42.5

[1] Downslope groundwell.
[2] Upslope groundwell.
[3] Surface runoff sites.
[4] Bacteria colonies per 100-ml sample.

Slurry applications were continued after March 1973, but the applications were much less frequent. Intermittent analyses of groundwater samples were made through December, 1974. All test results for GW-2 and GW-3 are combined in Figures 12-14 to show parameter changes with time.

In October, 1971 after heavy rainfall, the nitrate nitrogen (Figure 12) and fecal coliform levels (Figure 14) for GW-2 abruptly increased; surface water contamination was suspected. In January, 1972, an attempt was made to seal the wells with bentonite clay to a depth of 6 feet below ground surface. GW-2 was then disinfected with chlorine bleach according to accepted well disinfection procedures.

The seals appeared to be effective until March, 1973, when 6 inches of rain fell on almost saturated soil. Immediately after this event, the nitrogen and bacterial levels of GW-2 increased markedly; and the nitrogen content of GW-2 continued to increase for

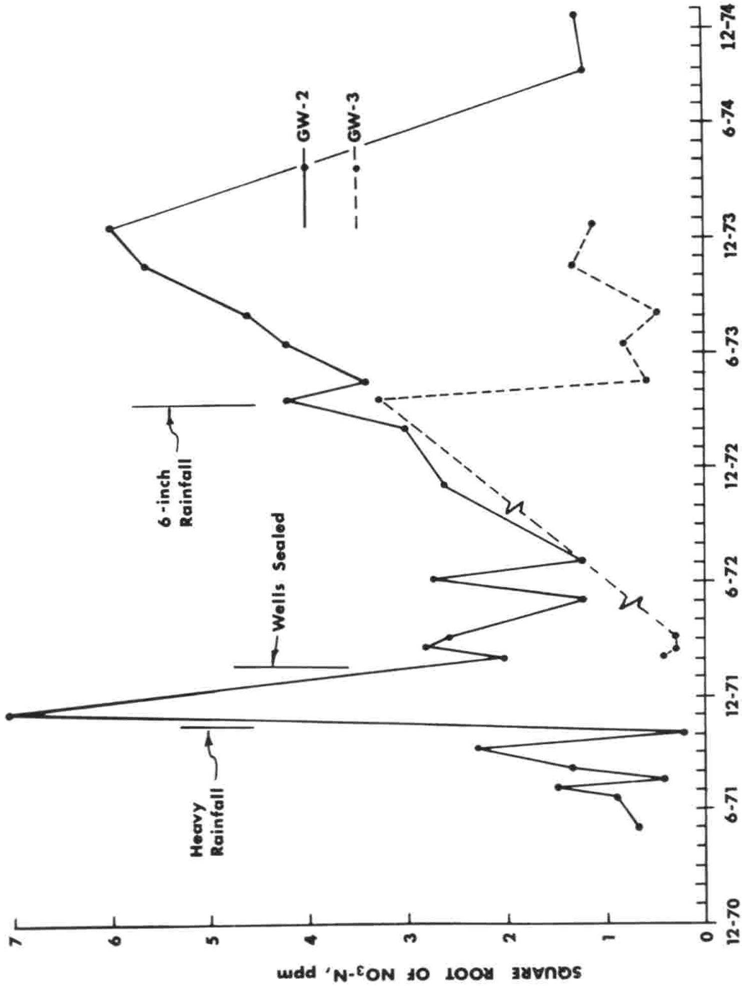

Figure 12. Changes in nitrate-nitrogen content of groundwater samples beneath slurry irrigation test area.

some time thereafter. The rainfall event similarly affected the bacterial concentrations of GW-3. The chloride concentrations of GW-3 also appeared to have been affected by the rainfall and manure runoff containing salt (Figure 13). Later disinfection of GW-2 again temporarily reduced bacterial concentrations (Figure 14); but with winter rainfall, they again increased.

By December of 1974, 2½ years after the frequent slurry applications had ended, nitrate and chloride contamination appears to have decreased markedly from the highest levels. However the fecal coliform sample counts remained high.

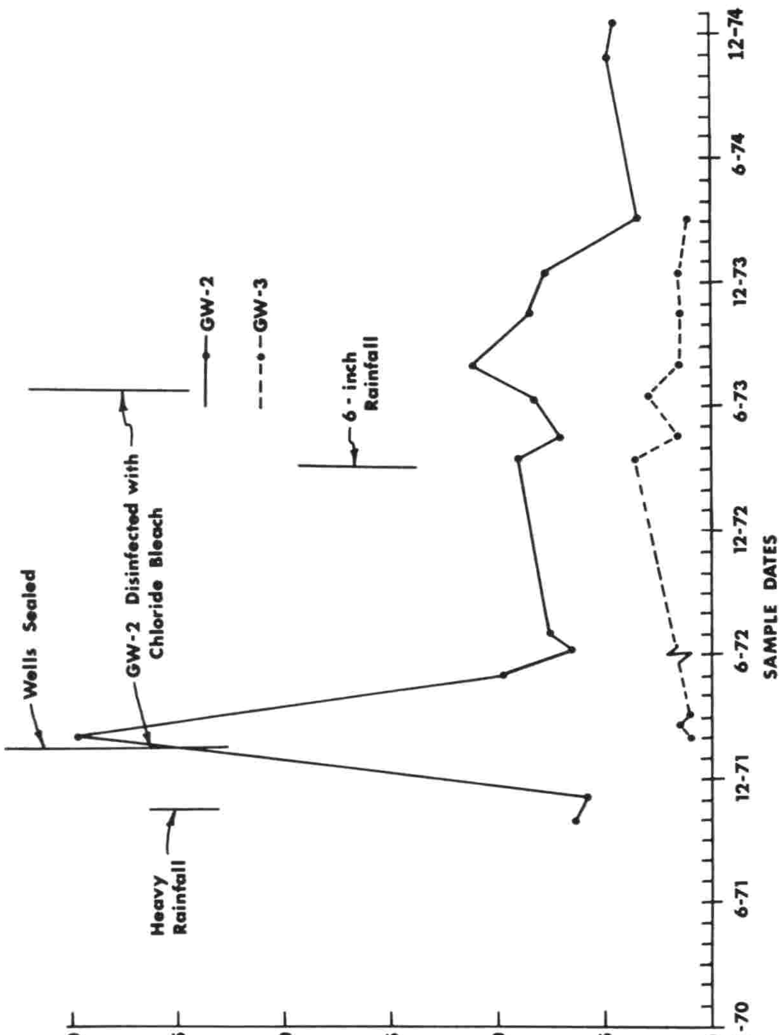

Figure 13. Changes in chloride concentration of groundwater samples beneath slurry irrigation test area.

Manure Slurry Irrigation and Soil Fertility

The test area received heavy applications of slurry as previously described between March, 1971 and March, 1973. Between then and December, 1974, irrigations were conducted less frequently. The test area and an adjacent area receiving no manure were maintained in pasture or sudan-sorghum throughout the test period. The sudan-sorghum planted in areas receiving and not receiving

manure were fertilized according to soil-test recommendations.

Mean results of six soil tests made during 4 years (Table 6) suggest that manure had little effect on soil acidity. The soil tended to become more acid between 1971 and 1974 which probably resulted because lime was last applied in 1968.

The phosphorus content of the manured plot increased from an average of 33 to 54 pounds per acre or 64%. The area receiving manure had more potassium (820 pounds per acre) than the area

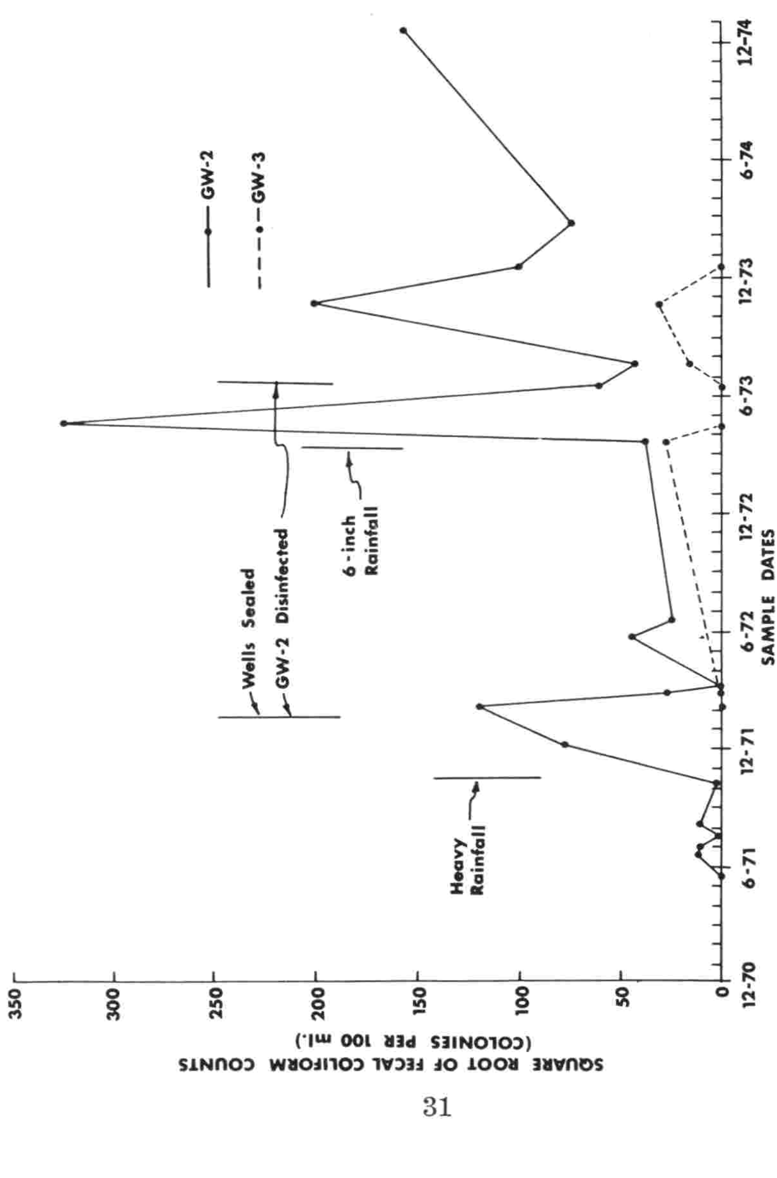

Figure 14. Changes in fecal coliform concentration of groundwater samples beneath slurry irrigation test area.

Table 6. Mean soil test results for Knoxville Main Station dairy manure slurry irrigation test area

Date	pH		Plant nutrients			
			Phosphorus		Potassium	
	Check[1]	Manure[2]	Check[1]	Manure[2]	Check[1]	Manure[2]
			Pounds per acre			
Apr. 1971	6.2	6.2	58	31	1,080	970
Sep. 1971	6.4	6.4	24	44	600	570
May 1972	5.9	6.6	20	32	640	650
Sep. 1972	5.4	5.7	23	57	530	890
Mar. 1973	6.0	6.8	23	80	530	800
Sep. 1974	5.6	5.8	48	79	725	1,020
Mean	5.9	6.2	33	54	680	820
Difference[3]	0.3		21		140	

[1] No manure; mean of three observations.
[2] Mean of six observations.
[3] Manure minus check

not receiving manure (680 pounds per acre), an increase of 21% attributed to manure. Nutrient differences between the two treatments tended to increase during 1973 and 1974. Continued heavy applications of manure without crop removal could cause elevated plant-nutrient levels.

Conclusions

1. Applications of 5.5 tons dry matter per acre per month in the slurry form presented no problems of solids accumulation on the ground surface.

2. Manure slurry or its drainage apparently entered the shallow groundwater on the downslope side of the test area and, to a much lesser extent, on the upslope side. Since the wells were sealed, entry of surface contamination through deep seepage and interflow is suspected. Continued high applications of manure slurry to a soil with medium to rapid internal drainage contributed—especially during periods of high rainfall—to the contamination of the shallow groundwater.

3. Rainfall runoff from the surface of the area receiving slurry irrigations exhibited high bacterial and chloride concentrations.

4. Waste application by slurry irrigation should not exceed crop fertilization rates and should be initiated only where enough land areas are available to minimize ground and surface water quality degradation.

5. Soil phosphorus increased markedly during 4 years of manure slurry applications, and soil potassium increased to a lesser extent.

6. Manure slurry had little effect on soil acidity.

Furrow Irrigation of Corn Silage with Dairy Manure Slurry

ROBERT S. PILE, JAMES B. WILLS, and JOHN I. SEWELL*

This study was conducted at the Cherokee Dairy Farm in Knoxville to determine the effects of furrow irrigation with dairy manure slurry on the corn silage yield of an East Tennessee stream terrace. The slurry irrigation facilities are described in the section titled "Sprinkler Irrigation of Dairy Manure Slurry."

Procedure

During the 1971 through 1974 growing seasons, a test plot on a stream terrace was established. The plot, planted to corn for silage, was 300 feet long by 120 feet wide and was graded in 1972 to achieve a more uniform irrigation slope. The irrigation slope after grading was 1.3%, sloping less than average for the first 100 feet of furrow length, and greater than average for the last 200 feet of furrow length. The soil on the plot was predominantly Etowah silt loam, a deep, well-drained soil. Irrigation furrows were formed by normal cultivation operations.

The slurry pumping system delivered slurry through 4-inch portable aluminum pipe and distributed it by 4-inch gated pipe. In irrigation, the gate assemblies were completely opened or removed from the pipe to prevent clogging by the fibrous material in the slurry.

Irrigation needs were determined by observing the crop, apparent soil moisture conditions, and precipitation data. Since the minimum discharge for the system was about 350 gallons per minute (gpm), excessive tailwater flowed from the short, relatively steep irrigation furrows. Individual furrow flows varied from about 18 to 25 gpm. The system was operated intermittently for 10- to 20-minute periods to control tailwater losses.

Corn silage yields were determined by hand-harvesting and

*Former Graduate Assistant, Former Graduate Assistant, and Professor and Associate Head, respectively, Department of Agricultural Engineering, Knoxville.

weighing green corn from two 50-foot, two-row subplots in the irrigated plot and two similar subplots from a nearby non-irrigated area.

Results and Discussion

Growing-season rainfall was near or above normal for all growing seasons considered (Table 7). However, seasonal fluctuations in rainfall were such that irrigation was needed at some time during each growing season. Eight manure slurry irrigations were conducted at the Cherokee Dairy Farm. Water applied was determined by measuring pump discharge, and water retention was determined by measuring the difference in soil moisture in the upper 15 inches of soil before and 24 hours after irrigation. The irrigation application efficiency was determined from these two values.

Table 7. Monthly precipitation totals at Knoxville during furrow irrigation tests

Month	Long-term	Precipitation in inches			
	mean	1971	1972	1973	1974
April	3.70	3.87	2.54	5.15	5.77
May	3.50	3.78	4.49	5.71	10.98
June	3.33	3.73	5.02	5.26	2.70
July	4.82	8.76	6.76	4.38	3.22
August	3.46	3.05	1.61	2.31	3.14
Total	18.81	23.19	20.42	22.81	25.81

Precipitation during June, July, and August 1974 was below normal; and four of the eight manure slurry irrigations were conducted during this growing season. Irrigation efficiencies for all seasons were low. The small increases in soil moisture and low application efficiencies in 1974 (Table 8) were attributed to the physical characteristics of the system and soil rather than to the nature of the slurry. Excessive tailwater flows accounted for most of the manure slurry losses. The furrows were shorter and steeper

Table 8. Manure slurry irrigation amounts and application efficiencies in 1974

Date	Irrigation application	Irrigation retention	Application efficiency
	Inches		Percent
June 26, 1974	2.26	0.98	43
July 3, 1974	1.76	0.83	47
July 9, 1974	1.69	0.72	43
July 15, 1974	1.59	0.78	49

than desirable, and the infiltration capacity of the soil was lower than desirable. Removal of the gate controls to prevent clogging resulted in higher discharge rates from the gated pipe. Application efficiencies were slightly improved for the last three irrigations in 1974 by operating the system for 10- to 20-minute intermittent periods.

The pumping system with the chopper-agitator in operation delivered a slurry with a solids content varying between 2 and 5%; and in slurry irrigations without operating the chopper-agitator, the slurry varied from 0.5 to 1.5% solids.

Corn silage yields (Table 9) were increased by slurry irrigation during all growing seasons considered. The yield increases were attributed to the combined effect of the manure slurry nutrient content and the water applied (Figure 15); however, the effect of the nutrients was not separated from the overall effect. The average irrigated plot yield was 19.5 tons per acre, and the average non-irrigated plot yield was 15.8 tons per acre—an increase ($P<0.10$) of 3.7 tons per acre or 22.6%.

Table 9. Corn silage yields of green matter from irrigated and non-irrigated test plots

Year	Yield (tons/acre)		Difference (tons/acre)
	Irrigated[a]	Non-irrigated	
1971	21.4	17.9	+3.5
1972	17.3	17.1	+0.2
1973	17.6	12.8	+4.8
1974	21.9	15.5	+6.4
Four-year mean	19.5**	15.8**	+3.7+

[a] Irrigations were conducted in 1971-1973 by Wills (1974) and in 1974 by Pile (1974).

**Yield variations between years were significant at the 99% level.

+ Significant at the 90% level of probability.

Conclusion

Dairy manure slurry irrigation of corn at the Cherokee Dairy Farm increased corn silage yields during all of the four growing seasons considered. This increase was attributed to the combined effect of plant nutrients and water. Growing-season rainfall was above normal during all seasons considered. The cultivator furrows carried the irrigation water and manure slurry satisfactorily. A layer of fibrous material and manure solids which formed at the soil-slurry interface may have restricted slurry intake.

Figure 15. Dairy manure slurry in furrow after irrigation has stoped.

From the standpoint of mechanical equipment, manure slurry irrigation by gated pipe appears feasible. However, the irregular and rolling topography of many cattle and dairy farms is such that few acres are conducive to furrow irrigation.

Liquid Swine Waste on Soils and Crop Yields

JOSEPH R. OVERTON, JOHN I. SEWELL, and G. M. LESSMAN*

From 1971 through 1974, liquid swine waste was applied on the surface of and injected into a Collins fine sandy loam and a Dexter loam soil on the West Tennessee Experiment Station. The Collins is a moderately well-drained, permeable, friable soil from young alluvium. The Dexter is well-drained terrace soil with a friable silt loam or loam topsoil and a firm silty clay loam subsoil.

From 1971 through 1973, a similar experiment was conducted on Hatchie and Almo soils employing different rates of waste than used on Collins or Dexter. Hatchie and Almo soils are more poorly drained and less permeable than the Dexter soils, even though they have topsoils with comparable textures and occupy similar terrace positions. Test plots were planted to corn and soybeans. Yield and soil-test data were obtained.

Waste Applications

Waste applications are reported as 1X, 2X, and surface (Tables 10-13). For 1X and surface applications, about 9,850 gallons of liquid waste per acre (1 gallon per foot of travel in 53-inch rows) were injected into or applied on the surface of the soils. The average nitrate-nitrogen and phosphorus contents of the slurry from all pit depths were 30 and 300 ppm, respectively. Thus the 1X and surface applications contained about 2.5 and 25 pounds of nitrate-nitrogen and phosphorus per acre, respectively. In the 2X applications, the rates were doubled. Injected applications were made once per year in each of the 4 years, and the surface applications were made once per year in 1972, 1973, and 1974. The soils were disked 6-8 inches deep and harrowed after waste treatments and just before planting. It was assumed that the soil was sufficiently

*Associate Professor, Department of Plant and Soil Science, Jackson; Professor and Associate Head, Department of Agricultural Engineering, Knoxville; and Assistant Professor, Department of Plant and Soil Science, Knoxville, respectively.

mixed as a result of these operations to prevent a "banding" effect. Adequate nitrogen (N), phosphorus (P), and potassium (K) were broadcast before the disking operation as suggested by soil test and current fertilizer recommendations.

Effects of Manure on Soils

To determine changes within the soil profile, samples were taken each year to depths of 24 inches in 6-inch increments at three randomly-selected points on the Dexter and Collins soils. Results in 1974 (Table 10) indicated that the manured areas on Dexter soil were somewhat higher in P, especially for the 2X and surface applications, than areas receiving no manure. Manure applications showed definite increases in K through the 0-12 inch depth. The 2X rate suggested increases in K through the 18-inch depth.

For the Collins (Table 10), P tests were variable possibly because of surface water movement over this soil in the spring. Potassium was increased through the 18-inch soil depth by the 2X applications. The same trend appears in the 0-12 inch depth for the 1X and surface treatments.

In other tests on Hatchie loam and Almo silt loam during the 1971 through 1973 period, total applications for the 3-year period

Table 10. Soil test results in October, 1974 after application of swine waste in 1971, 1972, 1973 and 1974 on Dexter and Collins soils

Depth	Application rates											
	pH[5]				Lb. P/A[5]				Lb. K/A[5]			
(inches)	None[1]	1X[2]	2X[3]	Surface[4]	None	1X	2X	Surface	None	1X	2X	Surface
	Dexter Silt Loam (2-5% slope)											
0-6	5.5	5.5	5.5	5.8	18	16	28	23	170	197	317	190
6-12	5.9	5.6	5.5	6.0	20	21	31	33	157	203	317	200
12-18	5.7	5.3	5.8	6.2	22	26	31	32	177	153	223	173
18-24	5.8	5.2	5.8	6.2	23	25	25	38	147	107	147	153
	Collins Fine Sandy Loam											
0-6	5.8	5.8	5.7	5.6	41	12	17	39	260	267	343	280
6-12	6.0	6.0	5.8	5.8	7	9	9	28	210	240	287	243
12-18	6.1	6.1	6.0	6.3	8	7	9	9	170	197	213	150
18-24	6.2	6.1	6.0	6.3	10	10	11	9	127	180	133	93

[1] No manure.

[2] IX—Manure containing 2.5 pounds and 25 pounds NO_3-N and P per acre, respectively injected into soil annually.

[3] Application injected at twice the 1X rate annually.

[4] Surface applications at 1X rate in 1972, 1973, and 1974.

[5] All values are means of three replications.

of 1X, 3X, and 6X were made. Phosphorus values for the Hatchie and Almo soils were high (60 pounds per acre) in the 0-6 inch depth, and P differences among treatments were small at all depths. For both soils, K levels in the 0-6 inch depth tended to increase with heavier waste applications. These K determinations averaged 212, 292, and 220 pounds per acre for the 1X, 3X, and 6X treatments, respectively, and were somewhat variable.

In the Almo soil only, K levels of the 12-18 inch depth increased markedly with heavier manure applications where 70, 165, and 150 pounds of K per acre were found for the 1X, 3X, and 6X treatments, respectively.

The manure treatments did not appear to affect soil acidity in any of the four soils tested.

Despite the several applications of swine waste, extractable NH_4-N remained at rather low levels for all soils as shown in Table 11. Any increases resulting from the application of this material seemed to manifest itself only in the 0-6 inch depth. This distribution pattern remained rather consistent whenever the samples were taken. Analysis of samples taken in 1972 gave similar results.

At the concentrations reported here, one would assume NH_4-N levels would not likely cause harmful effects on plant growth. These soils might handle even higher rates of swine waste and remain productive. For example, NH_4-N levels on the Hatchie and Almo soils at the 6X rate were no different than the check.

Effects of Manure on Corn Yields in 1971 and 1972

Details of the corn-yield studies were reported by Sewell and Overton (1973), and a summary of the results is given in Table 12.

No injury to stand or seedlings was observed in either planting regardless of row direction. In 1971, grain yields were reduced by manure applications on both soils. The untreated area on the Collins soil yielded 53.8 compared with 40.7 bushels per acre (difference significant at $P<0.05$) for the highest rate of manure. The difference on the Dexter soil was less, and sample-to-sample variation was greater.

In 1972 (Table 12), silage production was good (15.7 to 21.1 tons green matter per acre) ; but the grain yield was only about 60 bushels, although it was greater than in 1971. Based on green weight, manure in 1972 appeared to increase the silage yield on the Collins soil by 1 to 2 tons per acre, but it appeared to decrease the silage yield on the Dexter soil. However, oven-dry yields within a soil differed little. The Collins soil had slightly higher yields

Table 11. Extractable ammonium - N levels of four soils in October 1974.

Depth (inches)	Collins fine sandy loam[1] 0	Collins fine sandy loam[1] 1X	Collins fine sandy loam[1] 2X	Collins fine sandy loam[1] Surface	Dexter silt loam[1] 0	Dexter silt loam[1] 1X	Dexter silt loam[1] 2X	Dexter silt loam[1] Surface	Almo silt loam[2] 0	Almo silt loam[2] 3X	Almo silt loam[2] 6X	Hatchie loam[2] 0	Hatchie loam[2] 3X	Hatchie loam[2] 6X
	NH_4-N (ppm)													
0- 6	0.76	0.75	0.74	0.90	0.58	0.70	0.48	0.58	0.97	1.08	0.88	1.79	1.53	1.49
6-12	0.56	0.62	0.51	0.76	0.57	0.59	0.50	0.50	0.76	0.80	0.61	1.11	0.86	0.68
12-18	0.51	0.64	0.51	0.50	0.65	0.66	0.31	0.52	0.87	0.64	0.67	0.68	0.58	0.65
18-24	0.47	0.61	0.54	0.49	0.60	0.59	0.42	0.75	0.79	0.78	0.74	1.11	0.87	0.87

[1] Annual application in 1971, 1972, 1973, 1974.

[2] Annual application in 1971, 1972, 1973.

Table 12. Yields of corn following swine waste applications

Rate of manure[1]	Grain yield[2] 1971[3]	Grain yield[2] 1972[4]	1972 Silage yield[4] Green	1972 Silage yield[4] Oven dry
	Bu./a.[5]		T/A	
	Collins Fine Sandy Loam			
None	53.8[5]	66.4	18.72	5.12
1X	43.4	66.7	21.15	5.10
2X	40.7	65.6	20.26	5.16
	Dexter Silt Loam (2-5% slope)			
None	49.9	61.9	18.22	4.98
1X	43.5	58.2	15.74	4.72
2X	43.5	60.8	17.01	4.83

[1] See Table 10.

[2] Yield at 15.5% moisture; means of three sub-samples.

[3] Following swine waste application in 1971.

[4] Following swine waste applications in 1971 and 1972.

[5] The test indicated a significant ($P < 0.05$) difference between manure and no manure for the Collins soil.

than the Dexter. Each crop was planted quite late which would be expected to decrease yields. Also, crops were planted soon after manure was applied.

Some yield depression occurred after the first manure application on the Collins soil, but this was not evident after the second application in 1972. Seasonal factors may have contributed to this observation.

Effects of Manure on Soybean yields in 1973 and 1974

Pickett 71 soybeans were planted in June and harvested in November of each year. Additional fertilizer was applied at 0-26-26 pounds per acre. In August 1973, soybean plants on manured strips were darker green, shorter, and less well nodulated as compared with those on strips not manured. As the season progressed, the color difference diminished on the Collins soil, and to some extent, on the Dexter soil in depressions where moisture was available. Leaf samples were collected August 22 and analyzed (Table 13) for P, Mg, Ca, K, and N. Soybeans on the manured areas lodged near harvest time. Except for N, differences in the chemical content of the leaves were small.

The manure appeared to inhibit nodulation, but to supply nitrogen adequately. Natural nodulation and nitrogen supply developed adequately during the growing season on the Collins soil. On the Dexter soil, moisture limitation delayed the nodulation process and yields were lower ($P<0.05$) at 29.9 bushels compared with 33.4 to

Table 13. Yields of soybeans and nitrogen content of leaves following swine waste applications

Rate of manure[1]	1973 yield[2]	1974 yield[3]	Nitrogen content[4] of leaves
	Bu./a.[5]	Bu./a.[5]	In%
		Collins Fine Sandy Loam	
None	37.0	28.6	4.09
1X	37.6	28.5	4.59
2X	36.9	30.1	4.78
1X (Surface)[7]	37.6	—	4.90
		Dexter Silt Loam (2-5% slope)	
None	29.9[6]	30.0	3.26
1X	38.5	27.9	4.65
2X	33.4	27.8	4.71
1X (Surface)[7]	38.4	—	5.04

[1] See Table 10.
[2] Following swine waste applications in 1971, 1972, 1973.
[3] Following swine waste applications in 1971, 1972, 1973, 1974.
[4] On August 22, 1973.
[5] Yields are means of three subsamples.
[6] The test indicated a significant ($P<0.05$) difference between manure and no manure in the Dexter soil.
[7] Begun in 1972.

38.5 bushels per acre on other treatments. Nitrogen content of leaves was lower on the unmanured soils, especially on the Dexter.

In 1974, the soybeans appeared rather uniform across all treatments in color and size. Yields were very much alike in both manured and unmanured strips on both soils.

Summary

Corn stand or seedling injury was not observed. Some grain yield depression occurred in 1971 under poor growing conditions. In 1972 under more favorable conditions, silage yields were slightly increased by waste applications on an alluvial soil and slightly decreased on a terrace soil. Yields remained low both years because of late planting dates.

Effects of waste applications were not marked on soybeans except for nodulation effects observed in 1973. Soil test results indicated some increases in P and K after repeated applications and some penetration of K on Collins and Dexter to 12-18 inches, and to 18-24 inches, on the Almo soil. Manure was in addition to annual fertilizer applications; but soils testing medium to high were not manured.

The manure applied varied in N content and possibly in distribution and incorporation. Under these conditions, little effect on corn would be expected, although soybean nodulation was apparently inhibited in one case. Since soybeans had not been grown on the plots for a long time, use of a commercial inoculant would probably have obviated this condition.

Ammonium-N levels measured in this study never reached a level to be considered injurious to plant growth on any of the soils. Only a small increase was noted in the 0-6 inch level.

Repeated applications of 25 to 50 pounds of P per acre from manure, in addition to annual fertilization, to soils testing medium to high would be expected to raise test values for P somewhat, but would not necessarily increase crop yields.

Apparently, the manure treatments raised soil test values for K. However, the unmanured soils were not low in K, and under these existing conditions, crop yield would not necessarily be increased. With long-term applications of this quantity of swine waste, one should monitor soil test levels for P and K periodically to prevent problems associated with nutrient imbalance situations.

Effects of Agricultural Land Uses On Runoff Quality

JOHN I. SEWELL and JOE MAC ALPHIN*

Twenty-four test sites from five locations and representing much of Tennessee's agriculture were selected for study. The purpose was to evaluate the effects of several agricultural land uses on surface runoff quality near the areas of study. Grab samples were collected 4 to 10 times from each of the sites in 1971. The samples collected in sterilized bottles were packed in ice until laboratory analysis was begun.

Bacterial cultures were made according to the Millipore Membrane-Filter Technique for both total and fecal coliform counts. Biochemical oxidation demand and dissolved oxygen tests were conducted according to procedures recommended by the American Public Health Association. Nitrate-nitrogen and orthophosphate sample concentrations were determined by Hach procedures.

Sample test means for 18 selected sites are presented in Table 14. Details of the study were reported by Sewell and Alphin (1972). Biochemical oxygen demands (BOD) were lowest in samples from wooded and pastured watersheds; higher from heavily grazed pasture, resting areas, and farm ponds used by cattle; and highest in the aerobic lagoon. The 41.7 parts per million (ppm) BOD level of the lagoon may be compared with average BOD values of 200-300 ppm for untreated domestic sewage. The BOD levels of water samples from the wooded watersheds and all flowing streams were low.

All dissolved oxygen (DO) means exceeded the minimum standard for raw surface waters for public water supplies (4 ppm) as given by the Environmental Protection Agency (EPA, 1972). The lowest value, 5.5 ppm, was obtained from Site M3 where stream flow consisted largely of spring discharges which are known to have low DO values. At the Dairy Experiment Station, all DO levels of the flowing stream were high.

*Professor and Associate Head, and Graduate Assistant (deceased), respectively, Department of Agricultural Enginering, Knoxville.

Table 14. Water quality test result means for surface runoff samples from five Tennessee locations

Location	Site and description	Chemical tests in ppm				Coliform counts[1]	
		BOD[2]	DO[3]	NO_3-N[4]	PO_4[5]	Total	Fecal
Plant Science Farm, Knoxville	K1—runoff from terrace	8.3	6.4	0.6	1.3	16,600	13,800
Row crops—no livestock	K2—runoff from terrace	6.8	6.9	0.5	0.9	15,000	14,800
Cherokee Dairy, Knoxville	K3—near shade, after rain	13.8	6.1	4.5	7.1	330,000	41,000
Pasture and cow resting	K4—pasture runoff after rain	16.7	6.8	5.1	1.2	158,000	64,000
Dairy Expt. Sta., Lewisburg	L3—creek above dairy complex	1.6	8.9	0.6	1.1	2,200	310
Barns and pasture	L5—drainage, ungrazed watershed	1.3	8.6	0.3	0.8	1,400	200
near perennial creek	L6—creek just above dairy barns	3.2	8.8	0.6	1.2	1,800	1,200
	L7—creek below dairy barns	4.2	8.4	0.7	1.6	13,900	6,900
Middle, Tenn. Expt. Sta., Spring Hill	M3—stream 1 just below lagoon	1.7	5.5	2.3	3.6	2,900	460
Dairy, aerobic lagoon, pasture,	M4—stream 1, 0.3 mile below lagoon	2.4	8.3	3.3	1.7	4,700	1,100
cow resting area 0.3 mile below	M5—stream 2 below confluence	1.8	7.7	1.8	1.1	3,600	1.500
lagoon, and smaller stream 1	M6—stream 2 above confluence	2.9	8.0	1.1	1.0	2,500	1,800
flowing into large stream 2	M8—pond heavily used by cattle	10.0	7.9	0.2	0.1	600	——
	M9—aerobic lagoon	41.7	6.1	0.5	25.0	20,000	——
U.T.—A.E.C.[6], Oak Ridge	01—unpastured wooded watershed stream	2.5	8.5	0.1	0.1	1,500	——
Woods, fields, and pastures	03—pond heavily used by cattle	12.8	9.2	0.1	0.1	3,400	——
	04—pond on pastured watershed	8.9	9.0	0.1	0.1	6,500	——
	06—pond on unpastured watershed	3.9	7.6	0.2	0	2,500	——

[1] Bacterial colonies per 100-ml sample.

[2] 5-day biochemical oxidation demand.

[3] Dissolved oxygen.

[4] As nitrogen.

[5] Orthophosphate.

[6] University of Tennessee-Atomic Energy Commission Research Laboratories Farms.

Surface runoff samples from pasture and resting areas at the Cherokee Dairy contained more nitrate-nitrogen (NO_3-N) than any other samples. The only other levels exceeding 1.0 ppm were found in samples from the Middle Tennessee Experiment Station. Stream 1 flowing through a cow resting and grazing area contained 2.3 (M3) and 3.3 (M4) ppm nitrate-nitrogen. Stream 2 increased from 1.1 to 1.8 ppm downstream from the entry of Stream 1. The mean nitrate-nitrogen levels at all sites were well below the maximum allowable (10 ppm) for raw domestic water supplies (EPA, 1972). The aerobic lagoon (M9) contained far more orthophosphate (PO_4) than samples from any of the other sites tested.

The highest bacterial counts were found in storm runoff samples (K3 and K4) from a cow resting area at the Cherokee Dairy. At the Dairy Experiment Station, the bacterial counts increased immediately downstream from the dairy barn complex (L7). With the exception of this site, the bacterial counts of all flowing streams tested are within permissible standards for raw water supplies as established by EPA (10,000 and 2,000 colonies per 100-ml sample for total and fecal coliform, respectively).

Concentrations of livestock increased the BOD, orthophosphates, and bacterial counts of samples collected from nearby streams. Of 13 sites (data for eight sites presented in Table 14) examined on flowing streams, none had dissolved oxygen or nitrate-nitrogen levels which failed to meet EPA standards; and only one failed to meet the bacterial count criteria.

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