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ABSTRACT

Collection, storage, and ultimate land disposal of livestock feedlot runoff is becoming a more common practice as a result of increasing state and federal regulations prohibiting uncontrolled discharge of runoff. As a result of chemical, physical, and biological actions during the storage phase, the runoff applied to land from storage is often greatly different from that entering storage directly from the feedlot. This study was designed to observe those changes in the runoff during storage, and to evaluate their effect on land disposal practices. Six concrete paved feedlots with runoff control systems were studied, with emphasis on variations in nitrogen, phosphorus, and potassium in holding ponds used for storing runoff. Seasonal variations in nutrient content of the holding ponds result from precipitation patterns, nutrient losses, and other factors. Early spring dewatering of the holding ponds, followed by frequent summer dewatering if possible, will result in the best conservation of nutrients. Large differences in nutrient content of holding ponds were observed for different species of livestock, with stored swine feedlot runoff containing nearly eight times as much nitrogen as stored beef feedlot runoff.

Additional Index Words: livestock wastes, land disposal, nutrient losses.

While roofed-confinement production of livestock is becoming more common throughout the midwestern U. S., many open feedlots of all sizes continue to exist, and apparently will remain an important livestock production method. Some of these open feedlot facilities already have runoff control systems installed, some will not need them for various reasons, and many will be installing systems in the future, as state and federal regulations governing smaller feedlots become more rigidly enforced.

A significant amount of research is currently being conducted to develop new low-cost, low-management systems, but at this time the runoff control system that has proved most satisfactory in all areas of the country is one consisting of clean water diversion, runoff collection, a solids settling facility, a runoff holding pond, and pond dewatering equipment (MWPS, 1975a; USEPA, 1973). Systems of this type require a certain amount of management, mainly cleaning solids from the settling facility and dewatering the holding pond when necessary. As a minimum, spring and fall dewatering of the holding pond and periodic cleaning of the settling facility is recommended. Holding pond capacities and management are normally based upon hydrologic factors. An earlier study (D. H. Vanderholm, J. C. Lorimer, and S. W. Melvin. 1974. Field performance of selected beef feedlot waste-handling systems. ASAE Pap. no. 74-4015. St. Joseph, Mich.) indicated that the amount of management involved probably is not excessive from an operator standpoint, but this type of task usually has a low priority in a general farming situation and, therefore, is not accomplished as often as desirable.

Even though the primary purpose of feedlot runoff control systems is the prevention of water pollution, often overlooked is the management required to make the maximum use of the fertilizer nutrients holding ponds contain. While this may not seem important in many situations, a fertilizer benefit is essentially the only potential direct economic benefit resulting from installation of runoff control facilities. In many cases the value of the fertilizer nutrients in the runoff is substantial enough to justify some extra management to maximize their use.

There have been numerous studies in recent years designed to characterize feedlot runoff and to determine the causative factors for its characteristics and variations. These are well-summarized by the Midwest Plan Service (1975b). In the future, most feedlot runoff will pass through settling basins and be stored in holding ponds before it is ultimately spread on land. Runoff holding ponds should be differentiated from a similar structure, the anaerobic treatment lagoon. Holding ponds, unlike lagoons, are primarily designed to provide temporary storage of feedlot runoff and any treatment occurring during storage is a secondary benefit (or detriment if maximum utilization of nutrients is desired). The characteristics of the runoff after storage in holding ponds have not received much attention, in contrast to the widely studied contents and processes of waste treatment lagoons. However, since extensive biological decomposition, as well as other chemical and physical reactions, occur during storage of runoff in holding ponds, by the time dewatering occurs the contents are much different from the runoff which originally entered the pond. This paper presents the results of a project designed to study the characteristics of the contents of feedlot runoff holding ponds over yearly periods of time, to determine what changes take place and why, and to evaluate what effect these changes have, or should have, on the land application practices used.

The study was initiated in 1974 to evaluate installed runoff control facilities in terms of their management requirements, operator acceptability, and, in general, their

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effectiveness in preventing water pollution. Six commercial livestock operations—beef, dairy, and swine facilities—in central and northern Illinois were monitored for 2 years. Descriptive information concerning the feedlots where runoff holding ponds were studied is listed in Table 1. All the feedlots had concrete surfaces. This paper will report only the findings directly related to the characteristics and management of the holding ponds.

PROCEDURE

Each of the runoff control systems in the study consisted of a concrete settling basin with a gravity-drain or a pumped outlet, holding pond, and pumping equipment for holding-pond dewatering. Holding-pond capacities were based on Illinois Soil Conservation Service standards, which require a minimum storage volume of 381 mm (15 inches) of runoff from paved feedlot areas and 305 mm (12 inches) from earth-surfaced areas. Rainfall and runoff data were collected at all the locations. Nonrecording rain gauges and staff gauges for holding-pond stage readings were used at five locations; the sixth (Feedlot and Holding Pond 1) was instrumented more intensively with a recording rain gauge, a holding-pond stage recorder, and evaporation-measuring equipment.

Contents of the five holding ponds were sampled monthly, while the sixth was sampled weekly. Using a pond water sampler developed by Mitchell and Dickey (1973), samples were obtained near the pond centers at the surface and near the bottom. Bottom sludge samples were also taken periodically. Even though snow melt runoff events were not directly observed and measured, the holding pond contents sampled in early spring were due in part to snow melt. Fifteen physical and chemical measurements were made on each sample. All analyses were made following procedures outlined by the APHA (1971), except that ammonia and nitrate + nitrite nitrogen were determined by the method described by Bremner and Keeney (1965).

RESULTS AND DISCUSSION

Rainfall-Runoff

Holding-pond stage levels and rainfall measurements were used to calculate the rainfall-runoff relationship for Feedlot 1, as shown in Fig. 1. Supportive data obtained on the five feedlots without recording equipment were used for comparative purposes, but were not adequate for inclusion in this report. The rainfall-runoff relationship found in this study compares quite favorably with the results of Swanson et al. (1971), although their data were for earth rather than paved lots. The calculated regression line intercepts the abscissa at 7.50 mm (0.295 inches), which indicates that runoff would be expected after approximately 7.5 mm (0.3 inches) of rainfall. In addition to 19 rainfall events where runoff occurred during the observation period (spring, 1974, through fall, 1975, excluding the winter months), there were also 20 rainfall events, ranging from 2.54 mm (0.1 inches) to 10.9 mm (0.43 inches), from which no runoff occurred. These 20 events totaled 17% of the total rainfall received during the observation period. Another 17.6% of the total rainfall did not appear as runoff from those 19 events when runoff did occur; thus, runoff was approximately 65% of the total rainfall received.

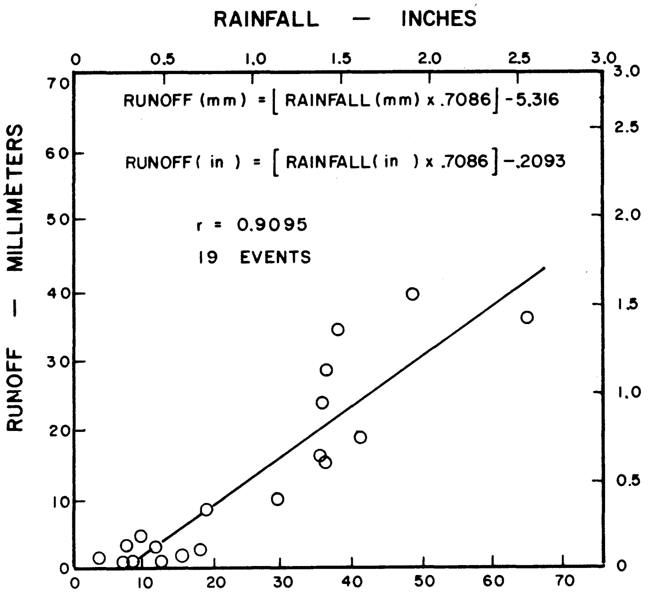

Fig. 1—Rainfall-runoff relationship for a paved beef feedlot (Feedlot 1).

Table 1—Characteristics of feedlots, study of water quality in runoff holding ponds, Illinois, 1947-74 (concrete surfaces)

Feed-lot	Operation	Construction date	Lot area m^2	Lot area ft^2	Lot capacity	Average number of animals on lot 1974	Average number of animals on lot 1975
					no. of animals		
1	Beef	1972	3,240	34,850	700	400	230
2	Beef	1972	1,390	15,000	300	310	200
3	Beef	1973	595	6,400	150	50	50
4	Beef†	1972	1,390	15,000	300	250	300
5	Swine	1973	2,150	23,100	1,200	900	1,000
6	Dairy‡	1973	929	10,000	70	55	55

† Holding Pond 4 also receives anaerobic swine manure pit overflow.

‡ Milking parlor wastes go into the runoff control system.

The rainfall-runoff data were substituted into the equation used by the Soil Conservation Service (Schwab et al., 1966) for estimating runoff volume in order to obtain an appropriate runoff curve number for concrete-paved beef feedlots in Illinois. This equation for estimating runoff volume is

$$Q = (I - 0.2S)^2/(I + 0.8S),$$

where Q = direct surface runoff in inches, I = storm rainfall in inches, S = (1000/N) − 10, and N = the arbitrary curve number varying from 0 to 100. The average N value calculated, using the data from the 19 events where runoff did occur, was 91.3, with a range of 69.4 to 98.5. This indicates that the selection of a runoff curve number near 90 would be appropriate when using the Soil Conservation Service method (Schwab et al., 1966) to estimate runoff volumes from paved beef feedlots in regions having climatic conditions similar to those in central and northern Illinois.

Nutrients

Ammonia nitrogen, Kjeldahl-nitrogen, and nitrate + nitrite nitrogen concentrations were measured in each holding pond sample. For the holding ponds under study, concentrations of nitrate + nitrite-N were quite low, and often near or at zero. Therefore, Kjeldahl-N can be used as the measure of total N in this study.

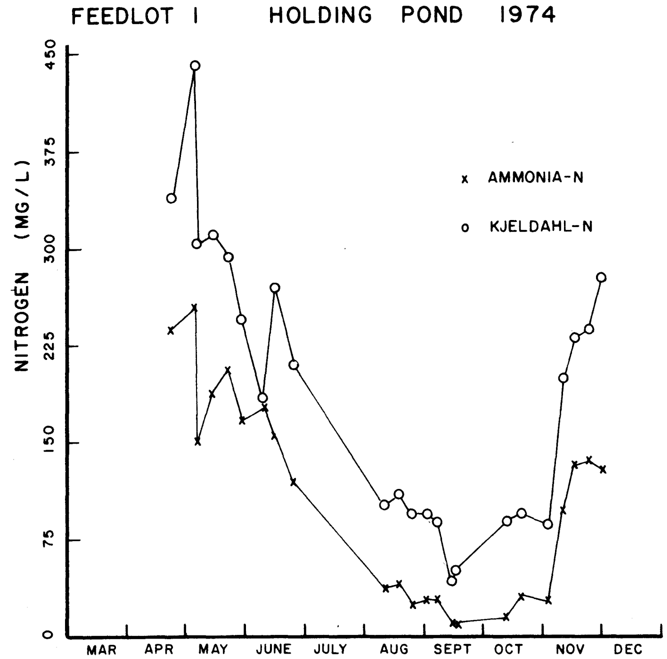

Fig. 2—Seasonal variation of ammonia-N and Kjeldahl-N in holding-pond water from a paved beef feedlot.

Figure 2 shows the seasonal variation in the ammonia-N and Kjeldahl-N in Holding Pond 1 during 1974. In 1975, Holding Pond 1 exhibited a similar seasonal variation, although the peak concentrations of N were not as high as those in 1974. The seasonal trends exhibited in Fig. 2 were observed in each of the six holding ponds studied. During the spring months of Mar. and Apr., ammonia-N and Kjeldahl-N were at peak concentrations. As water temperature began to increase, N concentration began to decrease, and continued to decrease into late summer. To illustrate more specifically the N loss observed in Holding Pond 1, a mass balance of the total N was calculated for a late summer period. Extensive monitoring during this period provided adequate data for mass balance calculations. The cumulative N loss from Holding Pond 1 for the period is shown in Fig. 3. Total N loss on a mass basis during this time was 134 kg (295 pounds). This represents a 52.9% loss of the total N in the pond at the beginning of the period plus N entering via runoff during the period. The decrease in N during the summer was largely attributed to volatilization of NH_3 from the pond surface, a process that has been well described by Koelliker and Miner (1973), who also point out that NH_3 concentration and NH_3 volatilization is temperature dependent, increasing with an increase in temperature. Denitrification could possibly account for some of the N decrease, but denitrification generally implies the reduction of oxidized N, such as nitrate and nitrite. Measurable concentrations of oxidized N were not observed in the ponds under study; therefore, denitrification probably plays only a small role in the N cycle of holding ponds. Except at the holding pond surface, where occasional measured redox potentials (E_h) of +300 mV and greater indicated somewhat aerobic conditions, redox measurements at the middle and bottom of the holding ponds were consistently < -50 mV, which is considered in the anaerobic range (Patrick and Mahapatra, 1968).

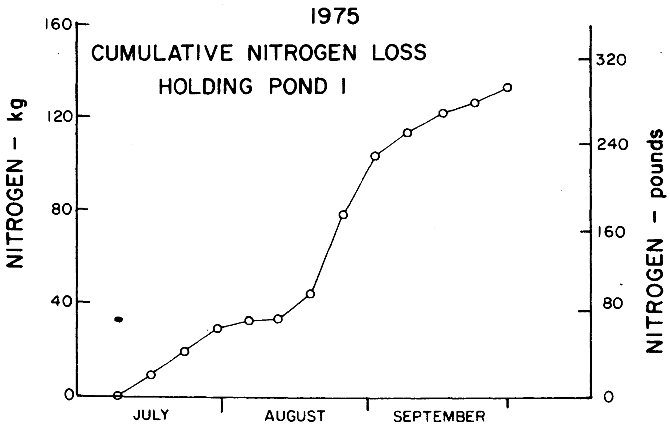

Fig. 3—Cumulative N loss from Holding Pond 1 during summer 1975.

The N concentration increase observed in late fall was largely due to the increased number of rainfall-runoff events. Also, the decrease in pond water temperature caused a decline in the microbial activity. With a lowered microbial activity, N entering the pond was not assimilated or decomposed as rapidly, thus allowing the total N concentration to increase without a corresponding increase in NH_3 loss. In contrast, higher temperatures during the summer promote more rapid decomposition, resulting in more conversion of organic N to the NH_3 form, which then can be lost through volatilization.

The seasonal variations of P and K concentrations in Holding Pond 1 are shown in Fig. 4. Phosphorus did not exhibit as strong a seasonal trend as N, but there was a marked decrease in the P concentration throughout the summer months. A mass balance calculation for the same time period as the N balance indicated that a 30.8% reduction of the P occurred during the observation period. The P decrease was probably due to the precipitation of insoluble P compounds (C. V. Booram, R. J. Smith, and T. E. Hazen. 1973. Some chemical and physical aspects of phosphate precipitation from anaerobic liquors derived

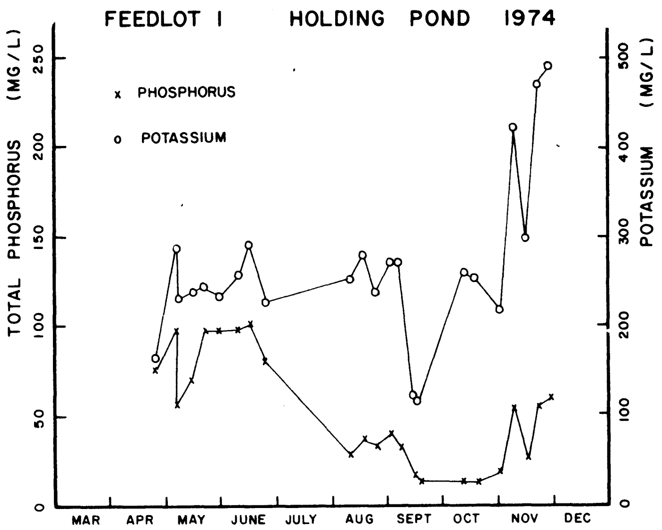

Fig. 4—Seasonal changes in P and K concentrations in holding-pond water from a paved beef feedlot.

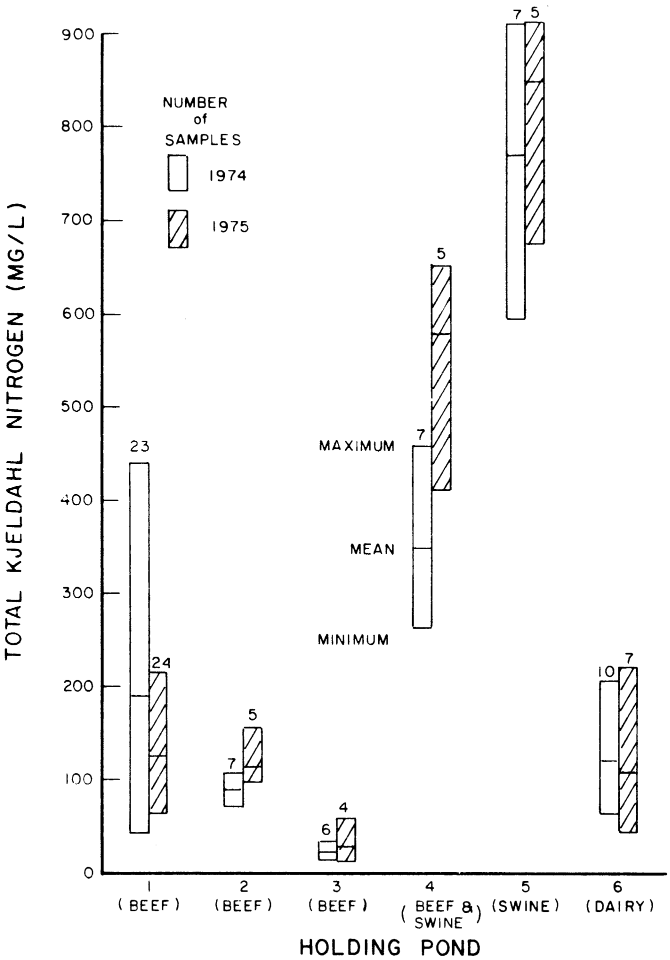

Fig. 6—Variation of N within a runoff holding pond among different feedlots and between years.

from animal waste lagoons. ASAE Pap. no. 73-4522. St. Joseph, Mich.). Phosphorus losses due to precipitation into the bottom sludge may also occur during winter months, but were masked by P additions in the runoff. Analysis of sediment material from holding ponds showed that the amount of P in the sediment was > 100 times the amount measured in the holding-pond water. The K concentration showed a slight increase throughout the summer, apparently being concentrated in the holding pond as a result of water evaporation. The large increase in K in late fall is caused by the increased number of rainfall-runoff events. Figure 5 has been included to illustrate monthly precipitation patterns during the 1974 and 1975 observation periods.

Besides the seasonal variation of N, P, and K, there are also large variations among different systems (Fig. 6, 7, and 8). Nutrient differences between beef and swine operations can largely be explained by the differences between the animals and their rations. Differences among beef facilities are a function of lot management and animal concentration on the feedlot. Lot management refers, in part, to the amount of manure allowed to build up on the lot surface before cleaning. A system with weekly lot scrapings would contribute less nutrients to the holding pond than a system that uses a monthly lot scraping. Previous studies have shown that, as the number of animals on the lot increases, and no change in lot management occurs, the amount of nutrients entering the holding pond when runoff occurs also increases (Gilbertson et al., 1971).

Figures 6, 7, and 8 also show that nutrient concentrations vary between years on each system. These variations are the result of year-to-year differences in rainfall and temperature, changes in the animal population of the system, changes in lot management, or a combination of these and other factors. The animal population in Feedlot 1 during 1974 was approximately 400 (See Table 1).

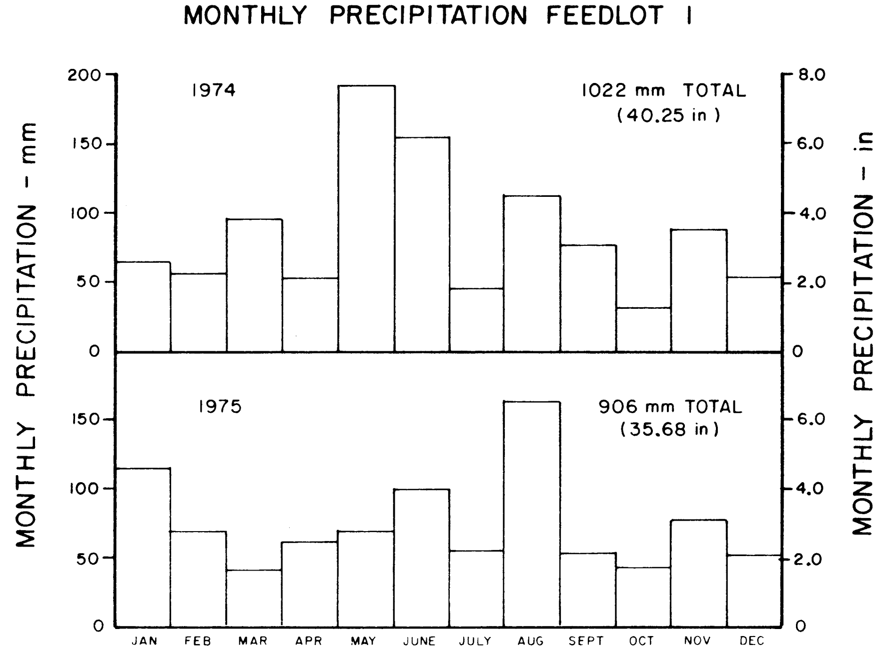
MONTHLY PRECIPITATION FEEDLOT I

Fig. 5—Monthly precipitation distribution at Feedlot 1 during the study period.

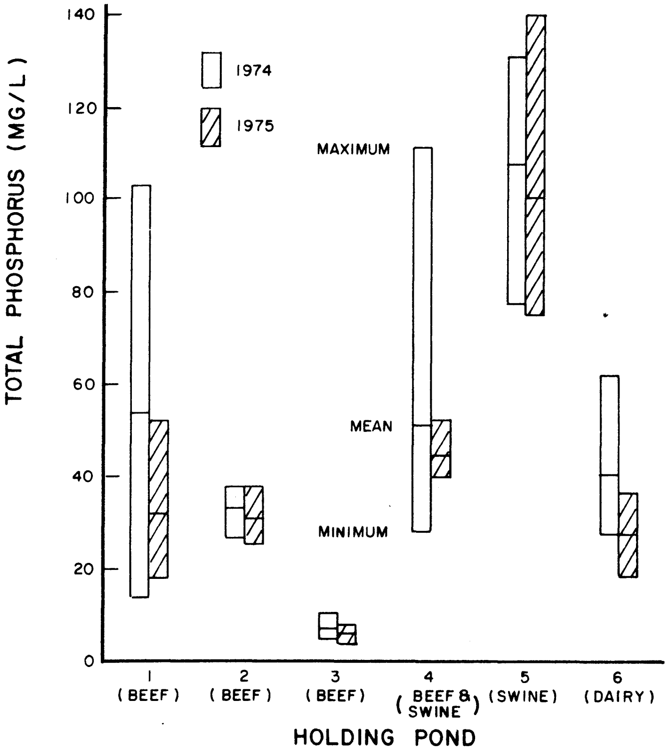

Fig. 7—Variation of P within a runoff holding pond among feedlots and between years.

This was reduced to about 230 in 1975 without an appreciable change in lot management. This reduction in animals resulted in a sharp reduction of the N and P, and some reduction in the K concentration. A similar reduction in animal numbers occurred in Feedlot 2 (from 310 in 1974 to 200 in 1975), but the management level was also reduced from monthly scrapings in 1974 to once every 3 months in 1975. With the reduced level of lot management in 1975, solids were allowed to accumulate on the feedlot surface, resulting in a greater N and K concentration in the runoff water. The animal population of about 50 in Feedlot 3 was relatively constant during both 1974 and 1975. During 1974 the lot was cleaned on a monthly basis but was not cleaned at all during 1975, resulting in N and K concentration increases in Holding Pond 3. With a thick manure pack on Feedlot 3, the P was probably held on the lot when runoff occurred, resulting in lower P concentrations in Holding Pond 3 during 1975.

Table 2 lists the percent of total N in the NH_3 form. Differences among the systems are large, and explanations for these variations are similar to those explaining N concentration differences. Having a high percentage of the N in the NH_3 form has both advantages and disadvantages. Nitrogen applied to a crop in the NH_3 form becomes almost immediately available for use by the crop, while N in an organic form needs more decomposition before becoming available. However, NH_3-N can be lost through volatilization to the atmosphere. Volatilization can be significant, especially if the holding-pond water is applied to the crop through a spray nozzle and has a pH > 7, which is often the case.

Table 2—Ammonia-N as an average percentage of Kjeldahl-N

Farm	Operation	Average percent 1974	Average percent 1975
1	Beef	44	43
2	Beef	50	42
3	Beef	29	10
4	Beef and swine	85	76
5	Swine	74	68
6	Dairy	41	32

Although a fertilizer benefit is possible through the effective use of holding-pond water, this benefit may not be large in terms of the total area fertilized. In central Illinois the average annual precipitation is 914 mm (36 inches). Approximately 65% of this precipitation, or 594 mm (23.4 inches), will occur as runoff from a paved feedlot surface. Feedlot 1, which has a lot area of 0.32 ha (0.8 acres), would then have an average annual runoff volume of 19.2 ha-cm (18.7 acre-inches). Assuming irrigation from Holding Pond 1 occurs in late Apr., the water would contain approximately 300 mg/liter of N, of which approximately 60% is in the NH_3 form. Multiplying the available N (NH_3) concentration by the runoff volume, the total quantity of available N in the runoff is 346 kg (762 pounds). The area that can be fertilized with N is

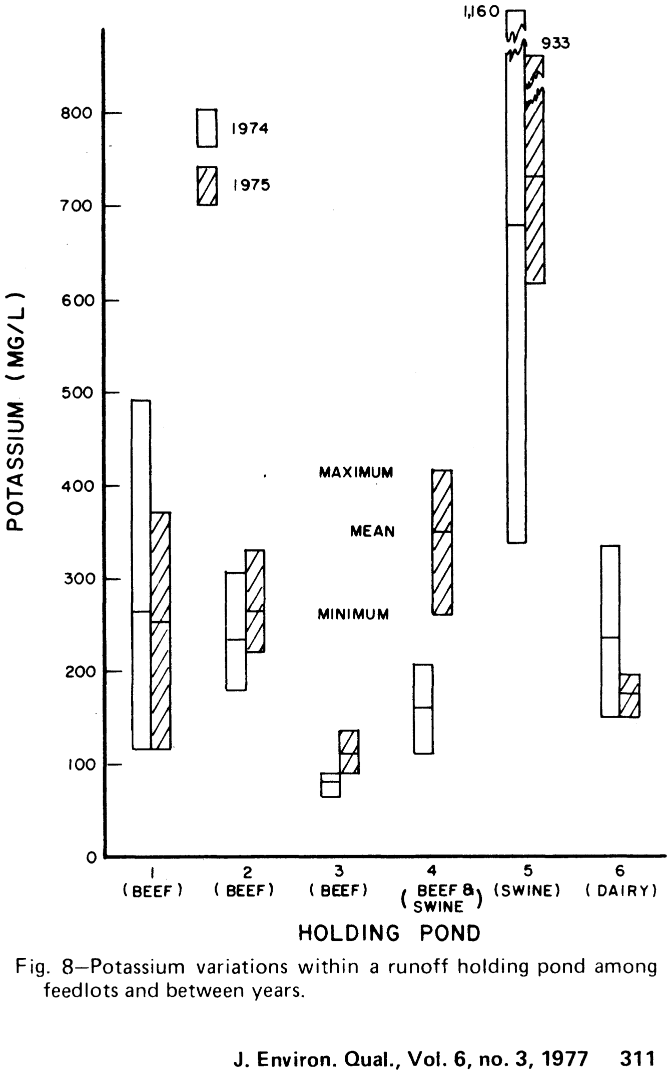

Fig. 8—Potassium variations within a runoff holding pond among feedlots and between years.

2.57 ha (6.4 acres), assuming an application rate of 135 kg/ha (120 pounds/acre) of available N. As the example indicates, runoff from a relatively large operation would be required to furnish enough N to fertilize an appreciable amount of cropland. The benefits of holding-pond water as a source of supplemental irrigation water was minimal, since the ponds are usually emptied in early spring, when supplemental irrigation is not necessary, and possibly even detrimental. Unless holding-pond water is stored until later in the summer, runoff quantities are usually too small to supply adequate volumes of water for supplemental irrigation, especially during dry years.

CONCLUSIONS

The nutrient content of stored feedlot runoff shows large seasonal variations. For instance, N concentrations in the holding-pond water were from 50 to 600% higher in Apr. and May than in Sept. and Oct. The large decrease in N concentration during the summer was attributed to volatilization of NH_3 from the runoff holding surface with increasing temperature. Phosphorus in the holding pond water also decreased during summer months, showing a more modest decline than N. Potassium concentrations essentially doubled from spring to fall, primarily as a result of concentration due to water evaporation losses.

Swine feedlot runoff stored in holding ponds contained nearly eight times as much N as did stored beef feedlot runoff (809 mg/liter vs. 106 mg/liter avg.). While beef feedlot runoff was high in organic N, most of the N in stored swine runoff was NH_3, a form readily available to plants. In addition, P and K levels were 3.5 to 4 times higher in stored runoff from open swine feedlots than from beef feedlots.

Year-to-year differences observed in the systems studied appeared to be closely related to lot management and animal population. Reducing the animals by approximately 60%, with no change in lot management, resulted in a similar reduction in N and P. Holding the animal population nearly constant and reducing lot management to a minimal level increased the N and K levels in the holding-pond water.

In order to gain maximum nutrient benefits, dewatering of the holding pond should occur in the spring. In addition to a higher N content in the spring, the stored runoff has a larger percentage of NH_3 in the spring than in the fall, and thus is more readily available to the plants. The N that enters the holding pond during summer will be lost at a greater rate than during fall, winter, and spring periods, and frequent dewatering of the holding pond during summer will minimize these storage losses. However, dewatering of the holding pond in the fall is still recommended in most situations to provide capacity for winter runoff storage. If only short-term runoff storage is practiced, the nutrient changes in the holding pond water will be of a lesser magnitude, but the timing of water application to the land may not result in optimum nutrient and water utilization by the growing crop.

LITERATURE CITED

1. American Public Health Association. 1971. Standard methods for the examination of water and wastewater. 13th ed. APHA, New York.
2. Bremner, J. M., and D. R. Keeney. 1965. Steam distillation of ammonium, nitrate, and nitrite. Anal. Chim. Acta. 32: 485–495.
3. Gilbertson, C. B., T. M. McCalla, J. R. Ellis, O. E. Cross, and W. R. Woods. 1971. Runoff, solid wastes, and nitrate movement on beef feedlots. J. Water Pollut. Control Fed. 43(3): 483–493.
4. Koelliker, J. K., and J. R. Miner. 1973. Desorption of ammonia from anaerobic lagoons. Trans. Am. Soc. Agric. Eng. 16(1):148–151.
5. Midwest Plan Service. 1975a. Livestock waste facilities handbook. MWPS-18. Midwest Plan Serv., Iowa State Univ., Ames.
6. Midwest Plan Service. 1975b. Livestock waste management with pollution control. N. Cent. Reg. Res. Pub. 222. Midwest Plan Serv., Iowa State Univ., Ames.
7. Mitchell, J. K., and E. C. Dickey. 1973. Device for obtaining water samples from small ponds or lagoons. Trans. Am. Soc. Agric. Eng. 16(3):544–545.
8. Patrick, W. H., Jr., and I. C. Mahapatra. 1968. Transformation and availability to rice of nitrogen and phosphorus in waterlogged soils. Adv. Agron. 20:323–359.
9. Schwab, G. O., R. K. Frevert, T. W. Ediminster, and K. K. Barnes. 1966. Soil and water conservation engineering. 2nd ed. John Wiley and Sons, Inc., New York.
10. Swanson, N. P., L. N. Mielke, J. C. Lorimer, T. M. McCalla, and J. R. Ellis. 1971. Transport of pollutants from sloping cattle feedlots as affected by rainfall intensity, duration, and recurrence. Proc. Int. Symp. on Livestock Wastes. Am. Soc. Agric. Eng. PROC-271, St. Joseph, Mich.
11. U. S. Environmental Protection Agency, Effluent Guidelines Div., Off. of Air and Water Prog. 1973. Development document for proposed effluent limitations guidelines and new source performance standards for the feedlots point source category. EPA 440/1-73/004.