Use of Animal Manure in Production of Wholesome Food

***H. H. Van Horn and P. W. Joyce**

INTRODUCTION

Nutrients in manure are recyclable. Applications of manure nutrients to plants that benefit from nutrient fertilization is the most used method to recycle. To avoid excessive applications of environmentally sensitive nutrients at inappropriate points, it is helpful to budget nutrient flow through the total animal-producing farm system (e.g.,Van Horn et al., 1991; 19%). Critical elements to develop a whole-farm nutrient budget to balance nutrient use in the environment include: 1) nutrients excreted by food animals, 2) potential nutrient removal by plants, 3) losses of nutrients within the manure management *system* and in fertility management for crop production, 4) combining steps 1 to 3 to assess whole-farm nutrient status, and 5) alternatives that permit export of nutrients off-farm, ifnecessary.

NUTRIENTS EXCRETED BY FARM ANIMALS

It has been demonstrated previously (Morse et al., 1992; Van Horn et al., 1994; 1996; Tomlinson et al., 1996) that original nutrient excretions are easily estimated by simple animal input-output comparisons. Thus, farmers are encouraged to use information from their feeding program to predict nutrient excretion. Accurate nutrient intake is the most important single source of information needed to estimate original nutrient excretions. Nutrition managers of large animal-food production units, who have access to computerized records of feed nutrient deliveries to animals, are key consultants in developing nutrient budgets. Records of food production sales off-farm along with measured or estimated nutrient content of the products provide the output component needed to accurately estimate manure nutrient excretions. Nutritionists also are skilled in balancing nutrients in diets so that animal nutrient requirements (e.g., Anon., 1984; 1989) can be met with as little excess of environmentally sensitive nutrients as possible.

Eliminating dietary excesses where they exist is the first step to reduce on-farm nutrient surpluses. It is well documented that many, perhaps most, dairy and beef cattle producers overfeed P; for example, dairymen often feed 0.50 to 0.60% P when NRC (Anon., 1989) recommends an average of about 0.42% for lactating cows. Reducing P to NRC (Anon., 1989) recommendations would reduce P excretion per cow by at least 20 lb/yr (Van Horn et al., 1996). The principles are the same for all animal species, i.e., reduce intake of environmentally sensitive nutrients to the fullest extent possible because excretions will be reduced to an even greater extent than intake.

NUTRIENT REMOVALS BY PLANTS AND AGRONOMIC ALLOWANCES

One generally acceptable philosophy of land application of manure is that nutrients can be applied slightly above the amounts removed by the crops harvested. A key question is, how much above the amounts of nutrients removed should be applied and what factors influence this? Nutrient removals by crops *are* easily calculated if we know dry matter (DM) removals and nutrient compositions on a DM basis. Table 1 illustrates the importance of N, P, and K concentrations on nutrient removals. Luxury consumption of nutrients (or increased concentrations in response to fertilization in the absence of a yield increase) have significant implications for nutrient budgeting even though potential for luxury consumption of P seems to be less than the potential with N and K The surest method for increasing P removal seems to be to increase crop yield by avoiding moisture stress and deficiencies of other nutrients.

Total nutrient removals with multiple-cropping are illustrated by a long-term research project at Tifton, Georgia, which was designed to identify a maximum, environmentally safe application rate of manure nutrients with a triple-cropping system (Newton et al., 1995). Flushed dairy manure nutrients were applied through center-pivot irrigation. The cropping system included 'Tifton 44 bermudagrass *(Cynodon dactylon* L.) into which corn *(Zea mays* L.) was sod-planted for silage in spring and 'Abruzzi' rye *(Secale cereale* L.) was sod-seeded in fall. Harvests included rye for grazing from about 1 December until 15 February, rye for silage about 20 March (corn planted the day following), corn for silage in mid-July, low-quality bermudagrass hay about 10 d later, and high quality bermudagrass hay or grazing until rye was planted again about 1 November. Although

[1]H.H.Van Horne and [2]P.W.Joyce. [1]Department of Dairy and Poultry Sciences and [2] Duval County Extension, IFAS, University of Florida, Gainesville, FL. Manuscript received 21 March 1997. * Corresponding author.

this is an example of one best-case scenario for nutrient removals, the Georgia data showed that harvests of 510 lb N and 90 lb P/a or more were achieved with application rates that were environmentally acceptable (Figure 1). These N and P removals were in a forage DM harvest of 12.9 ton/a annually which, for the example budget represented in Figure 1, was fed to 4.2 cows supplemented with purchased feeds to meet NRC protein requirements based on ruminally undegradable protein to minimize dietary N. The manure N was applied as fertilizer as quickly as possible to minimize N volatilization losses. Similar crop N removal rates have been reported for other environmentally acceptable manure utilization/forage crop systems, and even higher nutrient removals may be possible with an alternate system using two crops of corn silage per year plus winter rye or triple-crop sod-based systems utilizing high-yielding bermudagrasses.

Surface runoff and loss to groundwater are usually within acceptable limits but management practices must control these losses *so* that violations of state water quality standards do not occur. In Figure 1, values for budgeting of about 20 lb N/a passing to groundwater and 30 lb/a to surface water were assumed to be environmentally acceptable.

The budget illustrated in Figure. 1 is based on N. Thus, it assumes that in this location there is no environmental risk for surface runoff of P, which was applied in excess, or to allowing P to accumulate in the soil. Note also in this budget that manure N recovered as fertilizer was 646 lb or 70% of excretion (646/923). We think this is about the best possible recovery of manure N for fertilizer. If a P budget had been used, only manure from 2.3 cows could have been utilized in producing those crops which had a total removal of 90 lb P/acre (Van Hom et al., 1996). Thus, an appreciable amount of commercial fertilizer N would have been required to supplement manure nutrients and achieve proper balance for fertilizer N and P.

Denitrification is a bacterial process which converts nitrate in solution to N gas. It is dependent upon a bacterial energy source, usually in the form of soluble organic matter, and progresses most rapidly under high moisture and/or low oxygen soil conditions. For irrigated, highly diluted manure (less than 100 to 150 ppm N) the loss of ammonia during irrigation is often proportional to the evaporation loss of water. Denitrification losses are harder to estimate on the farm but can be large. Measured denitrification losses have been found to be in excess of 120 lb/a during some years when manure application rates were similar to that shown in Figure 1.

NUTRIENTS RECOVERED

It is important to differentiate between excretion and recovery. The difference has both environmental and economic implications. After excretion, manure may be stored wet, stored after being allowed to dry, flushed with water to a lagoon or holding pond, spread fresh on land, or spread in some other form at a later time. The N in urine, which may be about half of total manure N, is easily lost to the atmosphere as ammonia because it is excreted in the form of urea, or in poultry, asuric acid. Urease enzyme of bacterial origin is present almost everywhere, so N voided as urea is converted readily to gaseous ammonia (NH_3). The most important practical factors controlling ammonia volatilization losses are ammonia concentration (slower for dilute solutions) and surface area. Other important factors are temperature, pH (acid conditions reduce volatilization by converting NH,,a gas, to NH_4^+, which is not volatile), and air movement If voided on a paved surface in warm weather and only moderate air movement, essentially all of the urinary N will be lost unless the area is flushed frequently or the urine is diluted with water from cow cooling sprinklers or other sources. Most of the fecal N is in organic compounds and thus, is much more stable than urinary N.

A key measure needed on-farm to help evaluate manure management systems is the amount of N and P recovered and recycled relative to the amount excreted. Also, nutrient quantities are needed in order to know the dollar value realized when crops are fertilized with manure. Weighing enough loads of manure hauled to the fields to estimate amount and analyzing enough samples to predict N, P, and K composition are necessary. Nutrient recoveries are obtained by multiplying concentrations by load weights and number. If an irrigation system is used to distribute wastewater from a lagoon or holding pond, wastewater analyses are needed to go with the volume of wastewater distributed. Volume meters on irrigation pumps are important; if not available, gallons pumped must be estimated by hours pumped and estimated gallons/min from pump specifications. Some suggested estimates for preliminary budgeting if amounts recovered and compositions have not been measured are:

With quick application and incorporation, for example irrigation of flushed manure within 5 days after excretion to crops grown under sprayfield, N recovery: 65%.

Application of wastewaters from anaerobic lagoon with a 21-day or longer holding time, N recovery: 20 to 30%.

An average recovery for N in most manure handling systems: 40%.

For P, estimate recovery of 90% or more unless an anaerobic lagoon is used and a discount applied for what likely remains in the sludge in bottom of *the lagoon.* That amount could be as much as 50% in lagoons with 21-da or more average hydraulic retention time.

For K, estimate recovery of 80 to 90%.

Many underestimate N volatilization losses from manure and manure-containing wastewaters utilized for irrigation and fertilizer (e.g., Gallaheret al., 1995). When this occurs, crops are undernourished and nutrient removals are limited by N deficiency, P is overapplied and accumulates because P removals are less than budgeted.

WHOLE-FARM **NUTRIENT** STATUS: **NUTRIENT** BUDGETS

Figure 1 represents a specific nutrient (N) budget In this case, the cropping system was chosen first and a cow density selected wluch aclueved balance based on assumed N losses. In most cases, budgets are developed with animal numbers and animal production fixed and calculations are made to estimate nutrients that need to be utilized for crop production and the cropping system that can utilize them.

For example, let's assume an animal-producing farm recovers 24,000 lb N in manure per yr, 7,000 lb actual P per yr, and 14,000 lb K. Recoveries in approximately these proportions are common. Let's assume the triple-cropping program represented in Figure 1 is utilized, wluch removed 510 lb N/a annually in harvested crops Application would have to be somewhat greater than removals to allow for environmentally acceptable losses to volatilization of N after a field application, to denitrification, to groundwater, and to surface runoff.. In Figure 1, the allowance for N was 150% of removal if we calculate application as what went to the field in irrigated wastewater, i.e., 760 lb N applied versus 510 lb N recovered in crops harvested. With this *scenario,* it would take 27.6 a to utilize available manure N (21,000 lb N divided by 760 lb N applied/a). For comparison, let's assume recommended applications for P and K are 110% of crop removals. The Tifton, Georgia triple-cropping experiments (Newton et al., 1995; Van Horn et al., 1996) removed 90 lb P and 425 lb K/a. Thus, agronomic application rates would be 90 x 1.1 = 99 lb/a for P and 425 x 1.1 = 468 lb/a for K. The 7000 lb manure P would require 70 a of triple-crop production and the 14,000 lb manure K would require 30 a. This example, like almost all manure examples, shows the manure is P-rich relative to N, e.g., more than twice as much *crop* production was needed to utilize P than N. If soils can be permitted to build up P storage, it may not be a problem in the short-run to apply manure based on N content and permit P to accumulate in the soil. In the long run however, it is expected that over-application of P will be discouraged and perhaps prohibited. The value of the fertilizer nutrients recovered is greater when manure nutrients are applied utilizing a P budget as well (Henry et al., 1995). Usually K budgets require acreage intermediate to N and P budgets.

ALTERNATIVES THAT PERMIT EXPORT OF NUTRIENTS OFF-FARM

Often, food-animal producing farms do not produce sufficient crops to utilize nutrients on-farm. This will be true for most farms if P budgeting is required to avoid pollution and utilized to capture the economic value of manure. With P budgeting, many more farms will need to find ways to export manure nutrients for use as fertilizer on other farms.

Manure Application on Nearby Farms

Large food-animal producing units vary greatly in land resources that are available on the same farm to produce crops that will consume the manure nutrients produced. For example, most dairy farmers have sufficient forage needs *so* that traditionally they have maintained a sizeable farming operation in conjunction with the dairy. Thus, most dairies, but not all, can recycle their fertilizer nutrients on-farm if they increase sufficiently the intensity of crop production on the land they have. Large beef cattle feedlots and poultry producers, however, almost assuredly will need to export manure nutrients. Based on excretion estimates of about 100 lb N/steer-yr, a feedlot of 50,000 head with 80% occupancy will generate about 4,000,000 lb N/yr. If 50% of the N is utilized effectively as fertilizer (50% volatilized) for crops requiring 400 lb N/a, about 5000 a cropland is needed for utilization of the N. If the feedlot is in a *dry* area, irrigated cropland will be required or application rates reduced accordingly to match productivity of the *dry* land. One significant advantage of locating large feedlots in *dry* regions is that the manure can be scraped and hauled off-site very easily, as compared with feedlots located in wet regions. Earthen structures to contain runoff are very modest in size compared to high-ramfall areas.

Burning

Some regions that do not have sufficient crop production near the animal production unit have needed to find other means to utilize or transport manure nutrients off-farm. Burning manure is a possibility The first large-scale resource recovery project in the world to bum cattle manure as fuel to generate electricity was in the Imperial Valley of southern California. It was designed to utilize manure from the many beef cattle feedlots in the valley. Utilization of oultry litter for fuel is expected to approach 80% of the litter produced in the United Kingdom within 5 to 10 yr. When manure is burned, the ash nutrients still need to be managed accountably.

Composting

A significant amount of dried manure, composted manure, or a combination of dried and composted manure is bagged and sold as organic fertilizer. An example with dairy manure is a dairy cooperative in the Chino Valley in California which was set up to move manure off of large, intensive drylot dairies located in an urban area. Firms exist in the Southeast also that market manure-based fertilizers.

Composting is a logical way to process wetter manures (but not slurries) when livestock producers must create a product that must move off-farm and be stable enough when suburban users or agricultural users near urban centers want to utilize it. Composting is relatively costly, labor intensive, and some of the most valuable fertilizer constituent, N, is dnven off to the atmosphere during processing. Therefore, dairies and feedlots usually consider the process only if a marketable product is created that will help them remove the excess nutrients from the farm that they must remove. Several advantages include: aerobic composting reduces volume and converts biodegradable materials into stable, low-odor end products; thermophilic temperatures of 54°C (130°F) to 71°C (160°F), achieved in the process, kill most weed seeds and pathogens.

The physical form of cattle manures often does not provide optimal composting conditions. Fresh manure is too wet, and screened solids are usually too low in N content and other fertilizer nutrients. Thus, mixing materials from other sources may be required. Supplies of manure, bulking and drying agents, as well as market demand for the finished compost, should be investigated before animal producers invest in composting equipment.

DISCUSSION

Animal agriculture often is perceived by the public as having negative environmental effects, e.g., concern with swine units in North Carolina, Iowa, and Missouri; poultry units in Georgia, Maryland, Alabama, Arkansas, and Connecticut; cattle feedlots in Texas, Oklahoma, Kansas, and Colorado, dairies in Wisconsin, California, Florida, and Washington. Perceptions usually emphasize manure threats to water quality but nuisance concerns, especially odors and flies, are critical.

Agriculture is based on biological systems that effectively process manure nutrients and other biomass in cost-effective, environmentally acceptable ways. Most animal producers utilize these systems effectively and those with on-farm nutrient excesses are correcting them. Manure nutrients are manageable and the recovered fertilizer value can pay for a large part of the system costs if agronomic recycling is utilized. The public sector needs to be aware of this and to monitor agricultural systems based on real concerns and not perception so as not to impose unnecessarily costly processing methodology.

In many regions, the public is imposing more strict nutrient application requirements on manure than on commercial fertilizer. Actually, there appears to be less likelihood of manure nutrient losses to ground and surface water than from commercial fertilizer. Frink (1971) indicated that rarely are the N recovery percentages in crop plus soil from commercial fertilizers as high as with the three lowest manure applications reported in the Tifton, GA, experiments (Newton et al., 1995). The reasons that recoveries with commercial fertilizer systems (and some manure application systems) often are only 50 to 70% of the N applied is due to leaching or runoff during periods when crops are not growing, volatiliztion of ammonia N, denitrification, etc. Active roots are needed to utilize the fertilizer, which often is applied when the crop is planted, or before, rather than side-dressed in smaller applications as needed by the growing crop. One major advantage of sprayfield applications of manure-containing wastewaters, the method used in the Tifton, GA, experiments, is that nutrient applications are frequent, in small amounts, and most is in soluble form that can be taken up quickly by active roots.

The urban population may benefit from an assessment of the ability of agriculture to help process urban wastes. That avenue has potential to reduce costs of processing urban wastes and, at the same time, give better environmental accountability to the public sector. This already is happening, with some municipalities managing agricultural land or contracting with farmers to utilize treated wastewater (reclaimed water) and sewage sludge (residuals).

How important is it to create a partnership between farmers and the public to recover and recycle waste nutrients to create a more sustainable world? It is more important to consider how agriculture can help sustainability than it is to worry specifically about a sustainable agriculture. Food production on our remaining agricultural land must be increased. It is a challenge to do that and maintain all of the other environmental qualities that are important. Achieving those desired environmental qualities will require some regulations. However, skillful use of incentives and regulatory standards based ondesired outcome rather than process will give farmers much more freedom to increase food production while at the same time demonstrating environmental accountability.

LITERATURE CITED

Anonymous. 1984. Nutrient Requirements of Beef Cattle (6th Ed.). National Academy Press, Washington, DC.

Anonymous. 1989. Nutrient Requirements of Dairy Cattle 6th Rev. Ed.). National Academy Press, Washington, DC.

Frink, C.R. 1971. Plant nutrients and water quality. CSRS/USDA Agric Sci. Rev. 9(2):11.

Gallaher, R.N., T.A. Lang, and H.H. Van Horn. 1995. Estimation of N and P in Florida dairy wastewater for silage systems. pp. 72-76 *In* W. L. Kingery and N. Buerhing (eds.).Proc. 1995 Southern Conservation Tillage Conference for Sustainable Agriculture. Office Agric. Communic., MAFES, Mississippi State Univ., Mississippi State, MS.

Henry, G. M., M.A. DeLorenzo, D.K. Beede, H.H. Van Horn, C.B. Moss, and W.G. Boggess. 1995. Determining optimal nutrient management strategies for dairy farms. J. Dairy Sci. 78:693.

Morse, D., H.H. Head, C.J. Wilcox, H.H. Van Hom, C.D. Hissem, and B. Harris, Jr. 1992. Effects of concentration of dietary phosphorus on amount and route of excretion. J. Dairy Sci. 75:3039.

Newton, G.L., J.C. Johnson, Jr., J.G. Davis, G. Vellidis, R.K. Hubbard, and R. Lowrance. 1995. Nutrient recoveries from varied year round application of liquid dairy manure on sprayfields. *In* Proc. Florida Dairy Production Conf., Dairy and Poultry Sci. Dept., University of Florida, Gainesville, FL.

Tomlinson, A.P., W.J. Powers, H.H. Van Horn, R.A. Nordstedt, and C.J. Wilcox. 1996. Dietary protein effects on nitrogen excretion and manure characteristics of lactating cows. Trans.ASAE 39(4):1441.

Van Hom, H.H., G.L. Newton, and W.E. Kunkle. 1996. Ruminant nutrition from an environmental perspective: Factors affecting whole-farm nutrient balance. J. Animal Sci. 74:3082-3102.

Van Horn, H.H., R.A. Nordstedt, A.V. Bottcher, E.A. Hanlon, D.A. Graetz, and C.F. Chambliss. 1991. Dairy manure management: Strategies for recycling nutrients to recover fertilizer value and avoid environmental pollution. Florida Coop. Ext. Serv. Circ. 1016, Gainesville, FL.

Van Horn, H.H., A.C. Wilkie, W.J. Powers, and R.A. Nordstedt. 1994. Components of dairy manure management systems. J. Dairy Sci. 77:2008.

Table 1. Estimated range in N, P, and K harvests in crops at a given DM yield due to variation in composition.

	Yields (tons/a)[1]			N harvests		P harvests		K harvests	
Crop	Wet	DM	CP%	% of DM	lbla	% of DM	lbla	% of DM	lbla
Corn silage	18.0	6.0	9.0 to 13.0	1.4 to 2.0	168 to 240	.22 to .47	26 to 57	1.0 to 1.5	120 to 180
Rye or wheat haylage	6.0	3.0	16.0 to 21.0	2.6 to 3.3	156 to 198	.23 to .50	14 to 30	.7 to 1.5	42 to 90
Bermuda grass hay	6.0	5.0	11.0 to 18.0	1.8 to 2.9	180 to 290	.20 to .34	20 to 34	1.3 to 2.2	130 to 220
Forage Sorghum silage	18.0	6.0	8.0 to 12.0	1.3 to 1.9	156 to 228	.22 to .44	26 to 53	1.0 to 1.5	120 to 180
Alfalfa haylage	10.0	5.0	18.0 to 25.0	2.9 to 4.0	290 to 400	.22 to .49	22 to 49	1.5 to 2.5	150 to 250
Perennial peanut haylage	10.0	4.0	14.0 to 22.0	2.2 to 3.5	176 to 280	.21 to .39	17 to 31	1.5 to 2.2	120 to 176

[1]Ranges obviously exist in wet weight and dry matter (DM) yields. Farmers should use yield histories to estimate yields and their own composition history, if known.

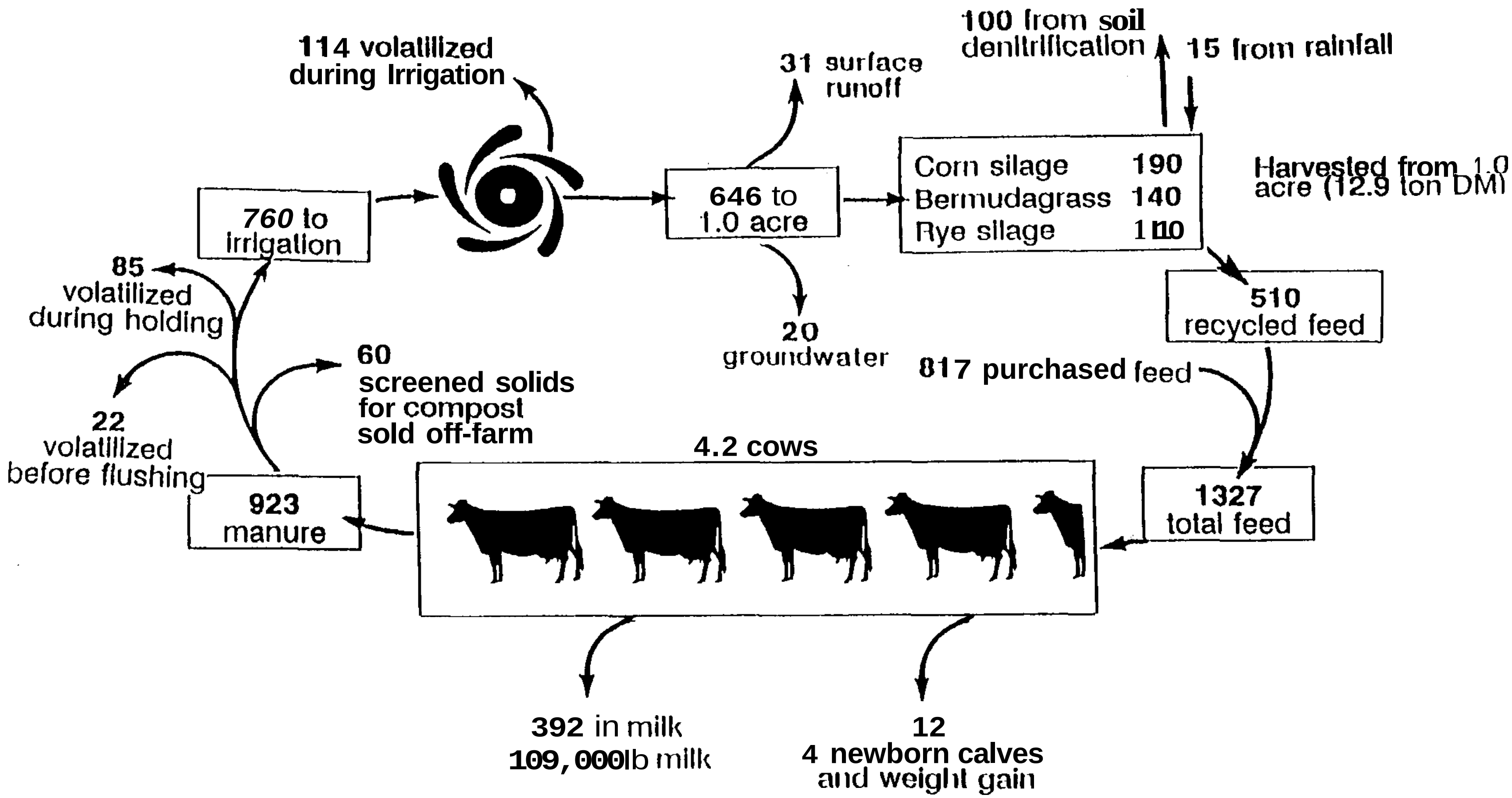

Figure 1. Example N budget for dairy manure system. Bold numbers represent pounds of N. Crop yield data are from experiments at Coastal Plain Experiment Station at Tifton, GA; excretion data from University of Florida experiments. Figure adapted from Van Horn et al. (1996).