NUTRIENT RECOVERIES FROM VARIED YEAR ROUND APPLICATIONS OF LIQUID DAIRY MANURE ON SPRAYFIELDS

by

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INTRODUCTION

As is true over most of the United States, dairy, livestock and poultry production in the Southeast have concentrated into units with greater animal numbers and, regardless of unit size, in localities with specialized infrastructure. This production is often on farms of relatively limited acreage or suitability for extensive manure distribution, and is potentially non-sustainable because of possible water quality impacts. Yet many rural areas are dependant upon the value-added nature of animal production for their economic prosperity.

We have investigated the utilization of manure on a frequent, year round basis in an attempt to reduce manure storage and its associated cost and potential for nutrient loss, odor and overflow; maximize capture of nutrients in crops; and reduce labor demands associated with seasonal manure application. Forage crops have been the focus of this research because production of superior forage continues to be a problem in the South, utilization of the whole plant has the potential for recycling larger quantities of nutrients than grain production, and forage rotations allow the maintenance of vegetative plants on the soil on an essentially continuous basis. Such systems may also more closely simulate natural ecosystems including high animal density (or be more similar to an intensive, rotational grazing systems than traditional harvested forage production).

PROCEDURE

The facilities and procedures have been described in a number of preliminary and progress reports (Davis-Carter et al., 1992; Hubbard et al., 1991, 1992, 1994; Johnson et al., 1991; Vellidis et al., 1991a, 1991b, 1993; Williams et al., 1991) and will be discussed only briefly.

The dairy manure irrigation study,initiated in 1990, was conducted on a 17 ac research site. At the start of the

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study, the land, comprised primarily of Tifton loamy sand soil (fine loamy, siliceous, thermic Plinthic Kandiudults), was typical of a new dairy site. The irrigated area (14 ac center pivot system) was divided into quadrants along topographic lines with each quadrant representing a treatment area (Figure 1). The quadrants received nitrogen applications rates of 178, 357, 535, and 714 lb ac^{-1} yr^{-1}, as liquid manure [approx. 110 to 150 ppm total N (TKN)] from a fresh water flushed, free-stall dairy. Applications (to all quadrants) were made each 7 - 21 days, depending upon weather and cropping operations.

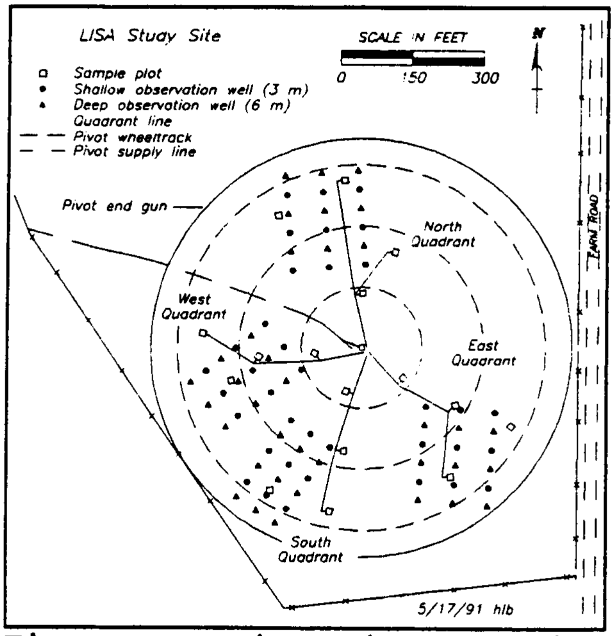

Figure 1. Dairy pivot showing the delineation of quadrants, the location of the sample plots and the location of the monitoring wells.

Four sampling plots (13 ft X 13 ft), where manure inputs (four samplers above the crop canopy at each plot), and crops and soil were sampled, were established within each quadrant. Three of these plots in each quadrant (Figure 1) contained high tension soil solution sampler (suction lysimeter) networks for obtaining water samples from the unsaturated zone of the soil (Vellidis et al.,1991a, 1991b). Each of these networks consisted of two arrays with each array consisting of solution samplers at depths of 1.6, 3.3, 4.9 and 6.6 ft. Each quadrant also contained a network of 18 ground water sampling wells consisting of nine wells set at 9.8 ft and nine set at 19.7 ft (Figure 1) (Hubbard et al.,1991, 1992). The manure application rates were selected so that the lowest rate should have been restrictive to plant growth and the highest rate should have been above that needed for maximum plant growth, based on N uptake rates calculated from previous experiments.

The cropping system, developed over the past decade by Coastal Plain Station scientists, was overseeding of abruzzi rye (*Secale cereale* L.) into Tifton 44 bermudagrass (*Cynondon dactylon* L.) sod in the fall, followed by minimum tillage planting of silage corn (*Zea mays* L.) into the bermudagrass and rye stubble in the spring, followed by summer crops of hay or silage from the bermudagrass (harvested monthly). Fresh water was applied to equalize the moisture received by each quadrant and was also applied to supplement crop needs during periods of high moisture demand.

The monitoring program determined the concentrations and cumulative amounts of nitrate N (NO_3-N), ammonium N (NH_4-N), TKN, phosphate phosphorus (PO_4-P), Total P, potassium (K), calcium, magnesium, and sodium applied through the waste, assimilated by the crops, stored in the soil (to 1 ft), or leached to shallow ground water. Water and nutrient movement through the unsaturated zone was monitored. Gaseous loss of N from the soil through denitrification was measured at monthly intervals with intact core samples (Lowrance and Smittle, 1988) taken to a depth of 1.6 ft adjacent to the sample plots.

RESULTS AND DISCUSSION

Crop nutrient uptake is shown in table 1. The yield response to increments of input diminished with increasing manure input. A somewhat similar pattern was observed for nutrient removal by the crops, except that the importance of rye in the rotation (for removal of N, P and K) increased as manure application increased. At the lowest application rate, bermudagrass was responsible for 60% of the N, P and K removed while at the highest rate, corn and rye removed similar amounts of N (about 35% each) and bermudagrass and rye removed similar amounts of K (about 30% each); bermudagrass accounted for 30% of the N and 15% of the P removed while corn accounted for 60% of the P and 40% of the K removed (with rye accounting for the remaining 25% of P removed). The subsequent rye crop removed 207, 148, 159 and 121% more N ac^{-1}, respectively, than removals during the first year, as shown in table 2. The greater N uptake by rye was associated with a 3° lower mean temperature, 2.7 inches greater rainfall, and 6% more solar radiation (equivalent to 12,000 calories more energy per in^2, mostly during February and March) over the rye season. This observation suggest that available sunlight may be a critical factor in nutrient uptake by the rye crop.

Nitrogen

The potential leaching and loss of N from land applied manure is of concern. An accounting of the N applied to this system during one cropping sequence is shown in table 3. Amounts of N removed by the crops were greater than that remaining, for all application rates. Denitrification was an extremely important consumer of N at the higher application rates. After removal of denitrification N, similar amounts of N remained for the three lower application rates while that for the highest rate was 375% greater. This has been taken as an indication that something(s) in the system broke down at application rates that lay somewhere between the two highest rates used. Yield was certainly one of these factors. After subtracting the change in shallow soil inorganic N over the cropping cycle, the quantity of unaccounted for N also remained essentially the same for the three lower rates and then jumped from this 45-55 lb ac^{-1} level to over 220 lb ac^{-1} for the highest rate.

Table 1. Uptake of N, P, and K by Crops in Response to Dairy Manure During 1991-92 Rotation.

Crop	Nutrient Uptake by Quadrant (lb ac^{-1}) N	P	K
		East	
Rye	30	6	43
Corn	26	13	44
Bermuda	88	32	129
Total	144	51	216
		West	
Rye	81	18	95
Corn	77	37	111
Bermuda	128	23	149
Total	286	78	355
		North	
Rye	96	21	102
Corn	123	78	173
Bermuda	168	29	151
Total	387	128	426
		South	
Rye	151	35	149
Corn	140	88	183
Bermuda	122	19	133
Total	413	142	465

Table 2. Nitrogen Uptake by Rye Forage Under a Minimum Tillage, Year Round Dairy Manure Irrigation System.

Location	Pounds N/acre 1991-92	1992-93
East	30	63
West	81	120
North	96	154
South	151	183

The average N concentrations of the crops is shown in table 4. The N concentrations of rye forage, the non-grain portion of corn, and bermudagrass forage increased significantly as manure application increased. These increases in N content, and increasing yields, resulted in similar proportions of the applied N recovered in crops for the three lower N application rates (table 5). If reasonable estimates of ammonia and denitrification loss are added to the recoveries shown in table 5, it is apparent that very little, if any, N was subject to leaching from the root zone under the three lower manure application rates. Soil NO_3-N, in five increments down to one foot, are shown in table 6. Increases were generally limited to the two higher manure application rates. After 2.27 years, inorganic N (NO_3-N + NH_4-N) in the upper 12 inches of soil amounted to 26, 37, 51, and 48 lb ac^{-1}, for the lowest to the highest manure application rates, respectively. This illustrates that the practice of applying relatively small amounts of manure on a frequent schedule, year round, to growing crops does not result in the accumulation of excess soil N.

Table 3. Mass Balance Accounting of Dairy Manure N (lb $ac^{-1}yr^{-1}$) Applied to a Three Crops per Year System (1991-1992 season)

N applied	Crop N	Balance	Denitrification	Balance	Soil NO_3 & NH_4-N (2.4 in)	Potential loss
230	144	86	29	57	7	50
410	285	125	62	63	6	57
615	387	228	165	63	16	47
768	414	354	119	235	13	222

Table 4. Average Nitrogen Concentration (%) in Crops Irrigated with Four Levels of Nutrients from Dairy Manure over 2.27 years.

	Crop			
Lb N/ac/yr	Rye	Corn grain	Corn forage	Bermuda
204	2.25	1.57	0.90	1.36
340	2.73	1.51	1.10	1.67
535	2.70	1.80	1.14	1.98
670	3.01	2.00	1.20	2.03

Table 5. Nitrogen Uptake by Forage Crops Under a Minimum Tillage, Year Round Dairy Manure Irrigation System (2.27 years total).

Quadrant	Total N applied (lb/ac)	Applied N harvested as crops (%)
East	462	86.3
West	799	95.8
North	1215	91.0
South	1521	76.1

Concentrations of NO_3-N in the soil water at 1.6 ft to 6.6 ft were determined after manure applications. values at 1.6 ft increased with time in the North and South quadrants, which received the two highest application rates. Concentrations of NO_3-N at 3.3 ft have increased in the South quadrant and tended to increase in the North quadrant, but to decrease in the East and West quadrants. Mean NO_3-N concentrations at the 4.9 and 6.6 ft depths remained close to pretreatment levels in all four quadrants. Specifically, in the South Quadrant which received the highest application rate, mean NO_3-N concentrations have increased from background levels of less than 2 ppm to above 10 ppm at 1.6 ft while they have remained relatively unchanged at near 13 ppm at the 6.6 ft depth. In the North Quadrant, mean NO_3-N concentrations have increased from 1 ppm to 9 ppm at 1.6 ft while concentrations remained constant at the other depths. In the West and East Quadrants, mean NO_3-N concentrations have decreased at the 1.6 and 3.3 ft depths while they have remained unchanged at the other depths (Vellidis et al., 1993b). NO_3-N is the primary nutrient of concern in ground water. NO_3-N in shallow ground water from 9.8 ft wells ranged from 2 to 22 ppm with a majority of samples exceeding 15 ppm. At 19.7 ft the NO_3-N ranged from 2 to 10 ppm, with most of the samples between 3 and 6 ppm. The concentrations of NO_3-N in shallow ground water at both of these depths have remained the same since prior to initiation of liquid manure applications without a trend for any manure treatments to increase levels of NO_3-N. No effects of any of the manure application rates have been detected in NO_3-N concentrations at depths greater than 3.3 ft. The continuous cropping sequence and frequent applications of relative low amounts of manure N apparently have not allowed large amounts of N to leach from the plant root zone and the leaching of NO_3-N in this soil has been relatively slow. Pre-treatment NO_3-N concentrations at 9.8 ft depth exceeding drinking water standards probably resulted from previous conventional single and double crop production systems on the site.

Table 6. Soil Nitrate (ppm) Under a Minimum Tillage, Year Round Dairy Manure Irrigation System After 2.27 Years.

Total N applied (lb/ac)	Soil depth (inches)				
	0-2.4	2.4-4.7	4.7-7.1	7.1-9.4	9.4-11.8
462	8.5	12.7	2.3	1.3	2.3
799	13.3	4.8	2.8	1.5	0.7
1215	26.3	6.1	5.4	6.8	7.7
1521	25.6	7.0	5.5	5.0	3.2

Phosphorus

Crop removal and denitrification losses accounted for a high percentage of applied N for the three lower application rates, a somewhat parallel situation existed for P.

Applications of P during the period illustrated in tables 1 and 2 were 45, 84, 126 and 146 lb ac^{-1} for the East, West, North and South quadrants, respectively. This data, as well as that for the following year are shown in table 7. There was essentially a zero P balance for all application rates for the first year. During the rye-corn-bermuda sequence of 1992-93, P applications were similar to that of the previous year, but P removals were lower at the two higher application rates. Also, at the two higher manure application rates, mean P concentration of the harvested forage dry matter declined from 0.50% and 0.57%, during 1991-92, to 0.34% and 0.35%, during 1992-93, respectively. The apparent inability of the cropping system to remove P from the shallow soil at higher crop yield levels may be related to the relative proportions of the crops produced at the different manure application rates, as shown in table 8. This relative decrease in P removal has been accompanied by a substantial increase in the concentration of P in the surface soil (0-2.4 in) after 2.27 years of manure irrigation (+37, +64, +85 and +95 ppm for the East, West, North and South quadrants, respectively, from an average beginning level of 30 ppm). (For the South quadrant, this amounts to an increase of 75 lb ac^{-1} for the top 2.4 inches and an increase of 170 lb ac^{-1}, for 12 inches of soil. The P concentrations in the in the 9.4 - 11.8 inch soil depth have changed little under either application rate, to this time.) At their present concentrations, surface soil P levels would not appear to be harmful, under most situations. If accumulation of surface soil P continues, deep tillage may need to be included in the system at some undetermined interval.

This study did not evaluate effects on runoff or surface waters, due to limited funding. However, phosphate concentrations in surface runoff from the north quadrant (535 lb N ac^{-1} yr^{-1}) of the pivot were measured in the range of 0.5-3.8 ppm in conjunction with an associated riparian forest restoration study (Vellidis et al., 1993, 1994). These concentrations were lower than reported as typical of pasture and rangeland runoff studies (1-5 ppm) (Khaleel et al., 1978) and considerably lower than those (4.9-9.0 ppm) reported by Westerman and Overcash (1980) for a pasture irrigated with 158 lb P ac^{-1} yr^{-1} (835 lb N ac^{-1} yr^{-1}) from dairy lagoon effluent.

Table 7. Phosphorus Uptake by Forage Crops Under a Minimum Tillage, Year Round Dairy Manure Irrigation System.

Location-year	Phosphorus, pounds/acre Applied	Removed	Balance	Forage P,%	2.4 in. Soil P
East					(14)
91-92	45	52	-7	.42	42
92-93	46	49	-3	.38	39
West					(30)
91-92	84	78	6	.40	70
92-93	82	79	3	.40	73
North					(33)
91-92	126	126	0	.50	77
92-93	129	89	40	.34	102
South					(18)
91-92	146	143	3	.57	74
92-93	180	93	87	.35	75

Table 8. Forage Yields from a Minimum Tillage, Year Round Dairy Manure Irrigation System (2 year average).

Location	Lb N/ac	Total DM t/yr	Percentage of Yield		
			Rye	Corn	Bermuda
East	214	6.2	17	29	54
West	376	9.8	20	45	35
North	564	12.8	18	50	32
South	712	13.0	22	57	21

An Alternate Cropping System.

Another pivot irrigation system of similar size to the one described above, is also connected to the same lagoon and fresh water system. This pivot, also divided into quadrants, is on a field that received essentially all of the manure effluent from the Coastal Plain Station dairy from the mid-1970's until 1991. After that time it received manure applications at rates and schedules similar to the system described above. The minimum tillage cropping system under this pivot for the past 2 years has been Abruzzi rye in fall, followed by temperate corn silage in the spring, followed by tropical corn silage in the summer to early fall period. Since this cropping system was expected to require greater quantities of N for success, some commercial N (90-100 lb ac^{-1} yr^{-1}) was applied via irrigation water to the corn crops, in addition to that supplied by the manure rates. This system of two pivot irrigators was operated such that when one pivot field was irrigated one week, the other was irrigated in a similar manner the next week. The tropical corn has required two applications of insecticide per year for control of leaf feeding moth larvae (applied as concentrate in oil, injected into irrigation line and applied with 0.18 inches of water).

Forage dry matter yields for this rye-corn-corn system are shown in table 9. Keeping in mind that this field has greater soil reserves of organic and inorganic N than that under the pivot with the rye-corn-bermuda, and that N was also supplemented, the total yields shown in table 9 are 12400, 8700, 3500, and 5700 lb ac^{-1} yr^{-1} greater than corresponding yields of the rye-corn-bermuda system for the lowest to the highest manure application rates, respectively.

Table 9. Annual Forage Dry Matter Yield From a Year Round Rye-Corn-Corn Cropping System Irrigated With Dairy Manure + Inorganic N (2 year mean).

		Estimated N application ($lb\ ac^{-1}yr^{-1}$)			
Crop	Units	295	440	640	755
Rye	lb/acre	3698	4747	3905	5052
	% of total	15	16	13	15
Temperate corn	lb/acre	11046	15396	15172	17506
	% of total	45	50	53	53
Tropical corn	lb/acre	9782	10448	9681	10738
	% of total	40	34	34	32
Yearly total	lb/acre	24527	30591	28758	33296

At least 50% of the Bermudagrass produced, using the rye-corn-bermuda system, was 12-14 week growth harvested immediately following corn silage harvest, and was not "dairy quality" feed. The quality of tropical corn silage was similar to that of a lower than normal grain content temperate corn silage (tends to produce only one substantial ear per stalk). Forage production was four to six tons ac^{-1} yr^{-1} greater for the rye-corn-corn system at the two lower manure application rates and 1.5 to 2.5 tons ac^{-1} yr^{-1} greater at the two higher manure application rates than the rye-corn-bermuda system. It appears that, when supplemented with N, the rye-corn-corn system is capable of recovering 100 to 150 lb ac^{-1} yr^{-1} more N at the lower manure application rates and 20 to 50 lb ac^{-1} yr^{-1} more N at the higher application rates, than the rye-corn-bermuda system. Corn appears to remove more P from the soil than bermudagrass. Supplementing N to manure based crop production during periods of high demand, rather than increasing manure application rates, should result in the application of less P per acre of sprayfield, and more balanced fertility.

It would appear that a sprayfield cropped in rye-temperate corn silage-tropical corn silage, sized for wintertime application rates and supplemented with fresh water and N during periods of high demand may approach optimum conditions for both maximum production of high quality forage and protection of natural waters. The question of what happens below ground level, when there is no deep rooted perennial (such as bermudagrass) in the system should be addressed.

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