

Intake and Digestibility of 'Coastal' Bermudagrass Hay from Treated Swine Waste Using Subsurface Drip Irrigation

J. C. Burns* USDA-ARS, North Carolina State University

K.C. Stone, P. G. Hunt, M. B. Vanotti, K. B. Cantrell, and D. S. Fisher USDA-ARS

Waste handling systems for confined swine production in the upper South (approximately 32–37° N and 79–93° W) depend mainly on anaerobic lagoons and application of the waste effluent to cropland. The main objective of this study was to evaluate the quality of 'Coastal' bermudagrass [*Cynodon dactylon* (L.) Pers.] hay receiving effluent generated from a raw swine waste treatment system designed to reduce P and K concentrations and delivered by subsurface drip irrigation (SDI) compared with hay produced from commercial N fertilizer. Eight treatments, consisting of commercial N fertilizer or effluent, each irrigated at two irrigation rates (75 and 100% of estimated evapotranspiration) and two lateral spacings (0.6 and 1.2 m), were compared with a control treatment of commercial N fertilizer without irrigation. Three harvests were taken in each of 2 yr and five of the six evaluated using wether sheep (30–45 kg). Greatest dry matter intake (DMI) per unit body weight occurred for the control vs. all irrigated treatments (1.94 vs. 1.77 kg 100⁻¹ kg; $P = 0.02$; SEM = 0.11). Among irrigated treatments, DMI was greatest from commercial N vs. effluent (1.81 vs. 1.71 kg 100⁻¹ kg; $P = 0.05$; SEM = 0.11). Dry matter intake was similar for the 75% rate treatments and the non-irrigated treatment (mean, 1.87 kg 100⁻¹ kg) but was reduced for the 100% rate (1.94 vs. 1.72 kg 100⁻¹ kg; $P = 0.03$; SEM = 0.11). Hay from the 75% rate was more digestible than hay from the 100% rate (527 vs. 508 g kg⁻¹; $P = 0.03$; SEM = 21). The SDI system functioned well, and lateral spacing did not alter hay quality. Treated waste from a raw waste treatment system was readily delivered by SDI at the recommended rate to produce bermudagrass hay of adequate quality for ruminant production systems.

ANAEROBIC lagoons continue to be the major waste handling system for swine finishing enterprises in the Upper South (approximately 32–37° N and 79–93° W). These systems have remained operational primarily through the use of swine lagoon waste effluent as a source of crop nutrients delivered by high-volume sprinkler irrigation systems. 'Coastal' bermudagrass is one of the major forage crops used for this purpose. Generally, N, P, and K have been considered the most agronomically and economically important nutrient elements of liquid waste, and limiting off-site losses of the former two elements is important for environmental protection (Sutton et al., 1982).

A previous study in the Coastal Plain of North Carolina examined production of Coastal bermudagrass with increasing N loading rates from lagoon effluent that ranged from 335 kg ha⁻¹ (the maximum recommended rate for dry land conditions in the Coastal Plains [Woodhouse, 1969]) to 1340 kg ha⁻¹ (Burns et al., 1985). Increased effluent application resulted in greater dry matter yields and nutrient concentrations in the forage. Increasing N rates reduced N recovery in the forage from 73 to 34% at the greatest loading rate. Likewise, phosphorus recoveries declined from 41 to 17%. Both N and P, as well as other elements, remained as potential pollutants in the surface water, ground water, or soil. In companion studies, King et al. (1985, 1990) reported accumulation of P down to 60 cm and nitrate-nitrogen (NO₃-N) below 90 cm at increasing N loading and suggested that ground water pollution could occur at the greater N rate (Westerman et al., 1985). After long-term (11 yr) effluent application, NO₃-N accumulation was reported in bermudagrass hay harvested in that study, and at the greater N loading rates, the NO₃-N concentration exceeded the toxicity level (>3.0 g kg⁻¹) for ruminants (Burns et al., 1990). These same general trends of increased N concentrations in forage were reported by Adeli and Varco (2001) when applying increasing rates of swine lagoon effluent to 'Alicia' bermudagrass and Johnsongrass [*Sorghum halepense* (L.) Pers.] on a silty clay texture soil in Mississippi.

Copyright © 2009 by the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. All rights reserved. No part of this periodical may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Published in J. Environ. Qual. 38:1749–1756 (2009).
doi:10.2134/jeq2008.0493

Received 26 Nov. 2008.

*Corresponding author (joe.burns@ars.usda.gov).

© ASA, CSSA, SSSA

677 S. Segoe Rd., Madison, WI 53711 USA

J.C. Burns, USDA-ARS and Dep. Crop Science and Dep. Animal Science, North Carolina State Univ. Raleigh, NC 27695. K.C. Stone, P.G. Hunt, M.B. Vanotti, and K.B. Cantrell, USDA-ARS, Coastal Plains Soil, Water and Plant Research Center, Florence, SC 29501. D.S. Fisher, USDA-ARS, Watkinsville, GA 30677. Cooperative investigation of the USDA-ARS and the North Carolina ARS, Raleigh, NC 27695-7643. The use of trade names does not imply endorsements by USDA-ARS or by the North Carolina ARS of the products named or criticism of similar ones not mentioned.

Abbreviations: ADF, acid detergent fiber; BW, body weight; CELL, cellulose; CP, crude protein; DMD, dry matter digestion; DMI, dry matter intake; EST, environmentally superior technology; ETC, calculated evapotranspiration; IVTD, in vitro true dry matter disappearance; NDF, neutral detergent fiber; SDI, subsurface drip irrigation.

Recent efforts have focused on minimizing the impact of livestock waste on the environment through the development of environmentally superior technology (EST). Such an EST system was developed to treat the raw waste stream and replace the traditional anaerobic lagoon (Vanotti et al., 2007). This EST facility processes raw waste through three steps, consisting of (i) solid-liquid separation, (ii) denitrification/nitrification of the liquid, and (iii) alkaline phosphorus separation to produce a treated waste effluent for crop application purposes (Vanotti et al., 2007). This system was recently demonstrated on-site (Vanotti and Szogi, 2008) and produced a treated effluent with concentration reductions of 98.3% for N and 95.4% for P. The effluent was evaluated for production of Coastal bermudagrass. This EST system was enhanced by the incorporation of subsurface drip irrigation (SDI) for the delivery of the treated swine wastewater (Stone et al., 2008). This system eliminates the potential for spray and drift and reduces odor and ammonia volatilization compared with land application by spray or furrow application. Similar systems have been used successfully in other regions of the USA to apply lagoon effluent to bermudagrass turf (Suarez-Rey et al., 2000) and to alfalfa (*Medicago sativa* L.) (Norum et al., 2001). Furthermore, the SDI system has shown increased water use efficiency in the South and, due to increased water demand by the general public, has the potential to replace overhead irrigation (Whitaker et al., 2008).

The SDI technology (including lateral placement), in combination with the waste treatment facility, was demonstrated by Vanotti and Szogi (2008) and has been used for the production of bermudagrass (Stone et al., 2008). Commercial N and treated effluent were delivered for the production of bermudagrass, with effluent resulting in greater yields than commercial N in the first year (8.7 vs. 6.8 Mg ha⁻¹) but similar yields in the second year (12.6 Mg ha⁻¹). Yields from SDI exceeded the county average in the first (7.7 vs. 7.1 Mg ha⁻¹) and second years (12.6 vs. 6.8 Mg ha⁻¹). Yields from SDI were similar to the non-irrigated treatment and between lateral spacings of 0.6 and 1.2 m (Stone et al., 2008).

The overall objective of this study was to determine the nutritive value using standard laboratory methodology and the forage quality, determined with sheep, of Coastal bermudagrass hay produced by Stone et al. (2008) using EST-treated swine lagoon effluent delivered by SDI technology. The specific objectives were to evaluate (i) commercial fertilizer compared with treated wastewater effluent as a nutrient source, (ii) two different SDI lateral spacings, and (iii) two irrigation application rates based on calculated crop water requirements compared with a non-irrigated control treated with chemical fertilizer.

Materials and Methods

The experimental site was 0.53 ha of a loamy, siliceous, subactive, thermic, Arenic Paleudults (Autryville loamy sand) soil with a well established stand of 'Coastal' bermudagrass [*Cynodon dactylon* (L.) Pers.]. The site had been previously used as a pasture that periodically received overhead irrigation of swine waste from a swine lagoon that services a 4400-head swine finishing operation located in Duplin County, North Carolina (35°05'

N, 78°02' W). The site was adjacent to an experimental swine wastewater treatment facility constructed and operated by a private firm (Super Soil Systems USA, Clinton, NC) to demonstrate EST to replace anaerobic lagoon treatment (Vanotti et al., 2007; Vanotti and Szogi, 2008). Swine manure, flushed from barns, was processed directly through the treatment facility. The solids and liquids were separated, followed by N removal as N₂ from the liquid phase with subsequent alkaline phosphorus removal (calcium phosphate) with the clarified effluent (pH 10.5) retained for crop application. The mean differences in concentrations of water-quality constituents in raw flushed manure compared with lagoon liquid or effluent from the treatment facility, as used in this study, were previously reported by Vanotti and Szogi (2008). Of special interest in this study was the reduction of the N and P fractions in the effluent known to be potential ground pollutants in the production of bermudagrass. An SDI system was installed for the delivery of the treated wastewater to the bermudagrass area (Stone et al., 2008).

Treatments consisted of treated wastewater (effluent) plus well water and granular commercial fertilizer plus well water, all applied via SDI at 75 or 100% of calculated evapotranspiration (ET_c). These four treatments were repeated using lateral spacing in the SDI system of 0.6 and 1.2 m placed at a depth of 0.3 m. This resulted in eight treatments, with a ninth treatment consisting of a commercially fertilized (345 g N kg⁻¹ ammonium nitrate), non-irrigated control. The seasonal N application rate for bermudagrass in this study was 270 kg ha⁻¹ for all treatments and was applied in three split applications of 90 kg ha⁻¹. This seasonal rate is consistent with the recommended rate of 250 to 336 kg N ha⁻¹ for the production of bermudagrass hay in this region (Chamblee et al., 1995). Initial application occurred in the spring and followed each of the next two cuts.

Irrigated treatments receiving commercial fertilizer received one or two applications of a 300 g N kg⁻¹ solution of urea-ammonium nitrate through SDI per cutting to deliver the 90 kg ha⁻¹ rate for each cutting. The swine effluent applied in this study had N concentrations reduced from 1584 to 23 mg L⁻¹ and P concentrations reduced from 576 to 29 mg L⁻¹ after processing by the treatment system (Stone et al., 2008). The treated effluent was sampled before each application, and the N concentration determined the quantity of wastewater to be applied to the treatments. At the time of each application, a second sample was collected from the effluent storage tank for N analysis to determine the actual application amounts. Nitrogen concentrations differed between years, averaging 465 mg L⁻¹ in 2004 and 94 mg L⁻¹ in 2005. This required one or two applications per cutting in 2004 and four or five applications per cutting in 2005 to supply the targeted N application rate. The amount of effluent and well water irrigated and total water applied (including precipitation) for each cutting is shown in Table 1. In the fall (2 December) before initiating the experiment, 'FFR 535' wheat (*Triticum aestivum* L.) was uniformly planted over the experimental site and harvested on 27 May. Wheat was planted over the experimental site on 29 November after the first year of the trial and harvested on 17 May. The use of wheat delayed the initial spring growth of bermudagrass.

Table 1. Treated swine lagoon effluent and well water applied to bermudagrass using subsurface drip irrigation and associated rainfall by harvest.

Harvest	Treatment†		Irrigation			Rainfall		
	N source	Irr. rate %	Effluent	Well water	Total	Effective	Actual	Total water
						mm		
<u>2004</u>								
Harvest 1 (23 June; Exp. † 1)	F	75	–	19.1	19.1	95.0	101.1	120.2
		100	–	19.1	19.1	95.0	101.1	120.2
Harvest 2 (10 Aug.; not evaluated)	E	75	16.6	2.5	19.1	95.0	101.1	120.2
		100	16.6	2.5	19.1	95.0	101.1	120.2
	F	none	–	–	–	95.0	101.1	101.1
	F	75	–	68.6	68.6	58.7	58.7	127.3
Harvest 3 (21 Sept.; Exp. 2)		100	–	80.3	80.3	58.7	58.7	138.9
	E	75	23.2	45.4	68.6	58.7	58.7	127.3
		100	23.2	57.2	80.4	58.7	58.7	139.0
	F	none	–	–	–	58.7	58.7	58.7
Harvest 1 (12 July; Exp. 3)	F	75	–	27.9	27.9	184.2	232.0	259.9
		100	–	30.0	30.0	184.2	232.0	262.0
	E	75	21.6	6.3	27.9	184.2	232.0	259.9
		100	21.6	8.4	30.0	184.2	232.0	262.0
	F	none	–	–	–	184.2	232.0	232.0
		75	–	83.8	83.8	120.6	120.9	204.7
Harvest 2 (11 Aug.; Exp. 4)		100	–	103.6	103.6	120.6	120.9	224.5
	E	75	66.0	17.8	83.8	120.6	120.9	204.7
		100	66.0	37.6	103.6	120.6	120.9	224.5
	F	none	–	–	–	120.6	120.9	120.9
Harvest 3 (13 Oct.; Exp. 5)	F	75	–	86.4	86.4	59.6	72.4	158.8
		100	–	106.7	106.7	59.6	72.4	179.1
	E	75	86.4	0.0	86.4	59.6	72.4	158.8
		100	86.4	20.3	106.7	59.6	72.4	179.1
Harvest 1 (12 July; Exp. 3)	F	75	–	114.3	114.3	124.3	149.4	263.7
		100	–	152.4	152.4	124.3	149.4	301.8
	E	75	95.2	19.0	114.3	124.3	149.4	263.7
		100	95.2	57.2	152.4	124.3	149.4	301.8
Harvest 2 (11 Aug.; Exp. 4)	F	none	–	–	–	59.6	72.4	72.4
		75	–	114.3	114.3	124.3	149.4	263.7
Harvest 3 (13 Oct.; Exp. 5)		100	–	152.4	152.4	124.3	149.4	301.8
	E	75	95.2	19.0	114.3	124.3	149.4	263.7
Harvest 1 (12 July; Exp. 3)		100	–	152.4	152.4	124.3	149.4	301.8
	F	none	–	–	–	124.3	149.4	149.4

† If irrigated, either 300 g kg⁻¹ urea-ammonium nitrate solution (F) or treated swine effluent (E) was applied; if non-irrigated, topdressed with granular (345 g N kg⁻¹) ammonium nitrate (F). Irr. rate, irrigation rate applied at 75 or 100% of calculated daily evapotranspiration values.

‡ Designates animal experiments 1 through 5.

Forage Source and Handling

Hay was cut three times each summer with a conventional mower to a 7-cm stubble, sun cured, and windrowed. Each plot was baled separately with a conventional square baler. Each bale was identified by a unique color-treatment code, and the baled hay was bulked across agronomic replicates by treatment to obtain sufficient dry matter for a feeding trial with sheep. Cuts were taken on 23 June, 10 Aug., and 21 Sept. 2004 and on 12 July, 11 Aug., and 13 Oct. 2005. After each cut, the nine experimental hays were transported to the North Carolina Research Service Animal Metabolism Unit in Raleigh, NC. The bales were stacked by treatment within each harvest on wood pallets in a metal barn designed for the storage of experimental hays and held for animal evaluation. Because of the large number of treatments ($n = 9$), each cutting was evaluated in a separate animal trial. Six harvests (three in each of 2 yr) were obtained, but the second harvest (10 August) in 2004 was baled prematurely and molded and was discarded. This resulted in the hays being evaluated in five animal trials. At the initiation of each experiment, hays were passed through a hydraulic bale press (Van Dale 5600; J. Starr Industries, Fort Atkins, WI) with stationary knives spaced at 10

cm. This process reduces hay into 7- to 13-cm lengths with essentially no leaf loss, aids in feeding, and minimizes the potential for hay to be tossed out of the manger. The processed hays were stored in carts before feeding.

Intake and Digestion

Procedure and Design

Five animal experiments were conducted, one for each harvest. Each experiment was conducted with different wether Katahdin sheep. In each experiment, a randomized complete block design was used with three to four (based on hay supply) animal replicates. Mean animal weights ranged from 30.4 to 46.6 kg ($n = 36$) in Exp. 1, 31.1 to 44.5 kg ($n = 26$) in Exp. 2, 28.4 to 42.8 kg ($n = 36$) in Exp. 3, 31.8 to 45.8 kg ($n = 33$) in Exp. 4, and 32.5 to 44.7 kg ($n = 33$) in Exp. 5 (overall SE, 3.2 kg). The experiments were conducted in a building constructed for small-ruminant research with temperature maintained between 13 and 24°C. Dry matter intake (DMI) and DMD estimates were conducted with conventional protocols (Burns et al., 1994). The animal care and handling procedures were approved by the North Carolina State University Institutional Animal Care and Use Committee (approval no. 03–047A). The animals were held

in digestion crates with free access to salt and water. When the sheep were initially placed in crates, they were fitted with a harness to facilitate fecal collection. After an initial adjustment period (14 d), allowing conditioning to the crates and harness, each sheep was randomly assigned to a treatment. The intake phase lasted 21 d and consisted of a 7-d adjustment to the experimental forage, followed by a 14-d intake phase, then followed by a 7-d digestion phase with daily total fecal collection occurring the last 5 d. At initiation of the digestion phase, a canvas collection bag was positioned on the harness and fitted with a plastic insert for total fecal collection. Digestible intakes of dry matter and fiber fractions were determined by multiplying the intake of each variable by its appropriate apparent digestion coefficient.

Feed and Sampling

All animals were fed at approximately 113% ad libitum intake in all trials. Hays were fed daily with the weight based on the previous day's intake. To adequately reflect the composition of the hay fed throughout the trial, a daily sample was obtained for each animal treatment and composited by week, and the 2 wk were combined for the 14-d intake phase. The unconsumed hay (weighback) from each animal was determined daily and composited for each experimental period. In the subsequent 7-d digestion phase of each trial, the feed and weighback samples were composited for the 5-d collection period and analyzed separately from the samples taken during the intake phase. All forage samples were thoroughly mixed, subsampled, oven dried (55°C), ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass a 1-mm screen, and stored in an airtight container at room temperature until analyzed.

In the digestion trials, feces were collected and weighed for each consecutive 24-h period. Feces were thoroughly mixed daily, and approximately 5% of the fresh weight was placed in a freezer (-14°C). At the end of the 5-d collection, the composite frozen samples were oven dried (55°C), weighed for dry matter determination, ground in a Wiley mill to pass a 1-mm screen, thoroughly mixed, subsampled, and stored at room temperature until analyzed. All intake and apparent digestion data are presented on an oven-dry matter basis. A separate forage sample was dried (43°C), ball milled, and stored for gross energy analysis.

Laboratory Analysis

All 'as fed,' weighback, and fecal samples were scanned in a model 5000 near-infrared reflectance spectroscope with WinISI, version 1.5 software (Foss North America, Eden Prairie, MN). The 'H' statistic (0.6) was used to identify samples with different spectra that were subsequently analyzed by wet chemistry, added to existing libraries, and used to develop near-infrared reflectance spectroscopy calibration equations to predict the various laboratory estimates related to nutritive value (see 'n'; Table 2). Concentrations of in vitro true dry matter disappearance (IVTD), crude protein (CP), NO₃-N, neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose (CELL), and lignin were determined on the "as fed" and, except NO₃-N, weighback samples. Fecal samples were analyzed for NDF, ADF, and CELL (Table 2).

Gross energy (not predicted by NIR) was determined using a LECO AC500 Isoperibol calorimeter (LECO Corp., St. Joseph, MI). In vitro true dry matter disappearance was determined by 48-h fermentation in a batch fermentation vessel (Daisy II²⁰⁰ System; Ankom Technology Corp., Fairport, NY) with artificial saliva and rumen inoculum according to Burns and Cope (1974). Ruminal inoculum was obtained from a mature Hereford steer fed a mixed alfalfa (*Medicago sativa* L.) and orchardgrass (*Dactylis glomerata* L.) hay. In vitro fermentation was terminated with neutral detergent solution in an Ankom 200 fiber analyzer to remove the residual microbial dry matter. Total N was determined colorimetrically (AOAC, 1990) with a Technicon Autoanalyzer (Bran and Luebbe, Buffalo Grove, IL), and CP was estimated as the product of 6.25 and total N. Nitrate-nitrogen analysis was conducted on the "as fed" samples only and was determined on a water extract by weighing approximately 200 mg of dry matter into a 125-mL flask and adding 50 mL of deionized water. Nitrate was determined on the day of extraction colorimetrically with a Technicon Autoanalyzer (Bran and Luebbe, Buffalo Grove, IL) equipped with an automated hydrazine reduction method manifold (Pulse Instrumentation LTD., Saskatoon, Saskatchewan, Canada). The hydrazine reduction method was performed according to Kamphake et al. (1967) and is detailed by USEPA Method 353.1 (Mueller and Smith, 1991) and expressed as NO₃-N. Fiber fractions consisting of NDF and ADF were estimated sequentially in a batch processor (Ankom Technology Corp., Fairport, NY), and sulfuric acid (72%) was used to determine CELL and lignin, all according to Van Soest and Robertson (1980). Hemicellulose was determined by subtracting ADF from NDF, the total cell wall constituent.

Statistical Analysis

The data were analyzed as a randomized complete block design with harvest providing a repeated measure (SAS Institute Inc., 2004). The mixed model included a random term for harvest, animals within harvest, and the harvest-by-treatment interaction. The only fixed effect was treatment. Means were compared by a set of orthogonal contrasts (non-irrigated vs. irrigated [I]; within I: lateral spacing [0.6 vs. 1.2 m], fertilizer vs. effluent, 75 vs. 100% I rate), including interactions (lateral spacing by N source, lateral spacing by I rate, N source by I rate, and lateral spacing by N source by I rate) within the ANOVA (8 df) along with two additional contrasts (non-irrigated vs. 75 and 100% I rate) to compare the overall impact of irrigation compared with non-irrigated production. Differences in all animal responses and in forage composition data were considered significant at $P \leq 0.05$. Simple Pearson correlation analysis was used based on the treatment mean (over animal replicates from all experiments) to examine relationships among variables. Correlations ($n = 9$) were considered significant at $P \leq 0.10$.

Results and Discussion

Some significant interactions were noted in the animal response and hay composition data. These interactions were attributed to non-parallel trends, or the differences were suffi-

ciently small to be of little biological importance and are therefore not discussed, and those contrasts are not reported.

Animal Responses

Dry Matter Intake

Sheep consumed more ($P = 0.02$; SEM = 0.11) of the non-irrigated (1.94 kg 100⁻¹ kg body weight [BW]) than the irrigated hays (1.77 kg 100⁻¹ kg BW) (Table 3). Within the irrigated treatments, animal intake of hay produced with N fertilizer was greater than hay produced with treated effluent (1.81 vs. 1.71 kg 100 kg⁻¹ BW; $P = 0.05$; SEM = 0.11) Table 3). Neither lateral spacing nor irrigation rate altered DMI. The comparison of DMI between the non-irrigated control and the irrigated rates showed no difference at 75% of ETc rate (mean, 1.87 kg 100⁻¹ kg BW), whereas DMI for the non-irrigated control, compared with the irrigated at 100% of ETc rate, was greater (1.94 vs. 1.72 kg 100⁻¹ kg BW; $P = 0.03$; SEM = 0.11). The DMI estimates obtained in this study are consistent with previous values obtained with sheep fed bermudagrass ranging from 1.70 kg 100⁻¹ kg BW for 'Tifton 44' to 2.05 for Coastal bermudagrass hays of 4-wk regrowth (Burns and Fisher, 2007). In a second year, with less mature 4-wk regrowth, the range was from 2.62 kg 100⁻¹ kg BW for Tifton 44 to 2.57 for Coastal.

Apparent Digestibility

Sheep digested hays similarly without or with irrigation and regardless of lateral spacing (mean, 517 g kg⁻¹) (Table 3). Although Type 2 statistical errors may have occurred ($P = 0.13$ – 0.06), there were no differences in apparent digestion of the dry matter or fiber fractions between the hays produced with chemical fertilizer or effluent. An exception was the ADF fraction, which was more digestible when the hay was produced with chemical fertilizer than with effluent (570 vs. 550 g kg⁻¹). Hays produced under irrigation at 75% of ETc were more digestible than those produced with the 100% of ETc rate (527 vs. 508 g kg⁻¹; $P = 0.03$; SEM = 21), as were each of the fiber fractions of the dry matter.

The apparent digestion of the dry matter and fiber fractions of the non-irrigated control did not differ from the irrigation treatment at 100% of ETc. However, although the dry matter digestion was similar between non-irrigated control and irrigated at 75% of Etc ($P = 0.07$), the NDF ($P = 0.02$; SEM = 20), ADF ($P = 0.02$; SEM = 22), hemicellulose ($P = 0.03$; SEM = 18), and CELL ($P = 0.02$; SEM = 20) fiber fractions were more digestible.

Digestible Intake

Digestible intakes of dry matter and the fiber fractions were greater for the non-irrigated hay compared with the irrigated treatments with the exception of hemicellulose ($P = 0.07$). This reflects the greater DMI noted for the non-irrigated hay because digestible intakes are the product of the DMI and the appropriate apparent digestion coefficients. Within the irrigated treatments, lateral spacing did not alter digestible intake of any of the hay constituents. Further, hay produced with chemical fertilizer gave greater digestible intakes of dry matter, NDF,

Table 2. The number (*n*) of samples (includes library samples and samples selected from the five experiments), range for each forage or fecal constituent predicted by near-infrared reflectance spectrophotometry, and associated SE of calibration (SEC) and SE of cross validation (SECV) over all experiments.

Item†	<i>n</i>	Range	SEC	<i>R</i> ²	SECV	<i>R</i> ²
		—g kg ⁻¹ —				
Feed and weighback						
IVTD	117	367–793	26.3	0.91	28.9	0.89
CP	121	53–227	3.16	0.99	4.1	0.99
NDF	120	654–828	8.5	0.95	11.0	0.91
ADF	118	292–455	8.2	0.94	10.6	0.89
CELL	119	223–383	5.9	0.95	7.4	0.93
Lignin	120	37–92	4.6	0.79	5.8	0.66
Feed only						
NO ₃ -N	404	0.12–2.90	0.12	0.96	0.14	0.95
Feces						
NDF	395	439–774	11.56	0.97	13.2	0.96
ADF	397	264–435	8.85	0.93	9.7	0.91
CELL	396	185–339	5.74	0.97	6.09	0.96

† ADF, acid detergent fiber; CELL, cellulose CP, crude protein; IVTD, in vitro true dry matter disappearance; NDF, neutral detergent fiber.

and its constituent fiber fractions compared with hay produced using treated effluent. This is again attributed mainly to the difference in DMI. In the case of irrigation, 75% of ETc gave greater digestible intakes of dry matter and NDF and constituent fiber fractions than 100% of ETc. Here the difference is attributed to digestibilities, which were significant (Table 3). In some cases, the differences in digestible intakes were small (i.e., fiber fractions) and probably of minor biological importance. In contrast to the results for apparent digestibility, comparison of the non-irrigated hay with the 75% irrigation rate showed no difference in digestible intakes of DM or any of the hay constituents, whereas the 100% irrigation rate resulted in reduced digestible intake of dry matter and the fiber fractions.

Hay Composition

Gross energy concentrations of the hays produced from the irrigated-fertilized treatments were greater ($P < 0.01$; SEM = 0.1) compared with the irrigated effluent-treated hays (Table 4). In the case of nutritive value, the IVTD of the experimental hays were similar among all treatments (Table 4). Only the apparent DMD of the hays with different irrigation rates differed, but generally increased precision is expected with IVTD estimates (respective CVs of 9.96 and 2.07%), making it easier to detect differences. In addition to this lack of significant effects, there was no correlation between the apparent DMD and the IVTD ($r = 0.45$; $P = 0.21$; $n = 9$). This suggests that factors other than digestibility are responsible for the observed differences in intake. Crude protein concentrations were greatest for the non-irrigated treatment compared with the irrigated treatments, but CP concentrations in all hays were adequate to meet the needs of replacement stock (100–110 g kg⁻¹) (NRC, 1985).

Nitrate-nitrogen concentrations are of interest relative to ruminant health. Concentrations were greatest ($P < 0.01$) for the non-irrigated treatment, averaging 1.11 g kg⁻¹ vs. 0.89 g kg⁻¹ (SEM, 0.09) for the irrigated treatments. The non-irrigated hay concentrations were sufficiently elevated in NO₃-N to fall

Table 3. Dry matter (DM) intake, apparent digestibility of dry matter, neutral detergent fiber (NDF) and fiber fractions, and their digestible intakes of Coastal bermudagrass hay from conventional N fertilization compared with treated swine lagoon effluent delivered by subsurface drip irrigation (oven-dry basis).

Spacing	Treatment†		DM intake kg 100 ⁻¹ kg¶	Apparent digestibility‡					Digestible intake§					
	N source	Irr. rate %		DM	NDF	ADF	HEMI	CELL	DM	NDF	ADF	HEMI	CELL	
			g kg ⁻¹					kg 100 ⁻¹ kg						
Irrigated	0.6 m	F	75#	1.82	547	597	587	607	641	1.00	0.83	0.39	0.44	0.36
			100††	1.81	513	570	562	577	624	0.94	0.79	0.38	0.41	0.35
	1.2 m	E	75††	1.69	515	564	556	570	620	0.86	0.72	0.34	0.37	0.32
			100††	1.77	510	561	545	574	613	0.89	0.75	0.35	0.40	0.32
		F	75‡‡	1.92	544	603	599	607	656	1.04	0.88	0.42	0.45	0.39
			100§§	1.68	493	542	531	551	597	0.83	0.70	0.33	0.37	0.31
	E	75††	1.76	503	555	541	567	608	0.85	0.72	0.34	0.39	0.32	
		100††	1.64	515	568	559	576	621	0.84	0.71	0.33	0.37	0.31	
Non-irrigated	F	none#	1.94	518	564	553	574	612	1.00	0.83	0.39	0.43	0.37	
Means (irrigated)	All		1.77	515	568	560	579	623	0.91	0.76	0.36	0.40	0.33	
	F		1.81	524	578	570	586	629	0.95	0.80	0.38	0.42	0.35	
	E		1.71	511	562	550	572	615	0.86	0.72	0.34	0.38	0.32	
	75		1.80	527	580	571	588	631	0.94	0.79	0.37	0.41	0.35	
	100		1.72	508	560	549	570	614	0.88	0.73	0.35	0.39	0.32	
	SEM		0.11	21	20	22	18	20	0.07	0.05	0.02	0.03	0.02	
Irrigated (I) vs. non-irrigated			0.02	0.99	0.65	0.60	0.70	0.40	0.02	0.04	0.03	0.07	0.03	
0.6 vs. 1.2 m			0.68	0.40	0.48	0.56	0.43	0.62	0.21	0.29	0.37	0.26	0.32	
I F vs. I E			0.05	0.13	0.06	0.04	0.10	0.09	<0.01	<0.01	<0.01	<0.01	<0.01	
I 75 vs. I 100			0.13	0.03	0.03	0.03	0.04	0.04	0.02	0.02	0.01	0.03	0.02	
Contrasts of interest (P)														
	Non-irrigated vs. I 75		0.41	0.07	0.02	0.02	0.03	0.02	0.63	0.47	0.43	0.53	0.66	
	Non-irrigated vs. I 100		0.03	0.33	0.59	0.69	0.51	0.90	0.01	0.03	0.02	0.04	0.03	

† Spacing is the distance between laterals. If irrigated, either 300 g kg⁻¹ urea-ammonium nitrate solution (F) or treated swine effluent (E) was applied; if non-irrigated, topdressed with granular (345 g N kg⁻¹) ammonium nitrate (F). Irr. rate, irrigation rate applied at 75 or 100% of calculated daily evapotranspiration values.

‡ ADF, acid detergent fiber; CELL, cellulose; HEMI, hemicelluloses; NDF, neutral detergent fiber.

§ Digestible intake is the product of each variables intake and its apparent digestion coefficient.

¶ Intake expressed on a body weight basis.

Each value is the mean of 18 animals.

†† Each value is the mean of 19 animals.

‡‡ Each value is the mean of 16 animals.

§§ Each value is the mean of 17 animals.

within the 1.0 to 1.5 g kg⁻¹ range designated as excessive for pregnant ruminants (Murphy and Smith, 1967; Parson, 1974). Such hay should only comprise 50% of the ration. None of the irrigated hays fell within the toxic range.

The NDF concentrations and constituent fiber fractions were generally similar between the non-irrigated and irrigated treatments and among irrigated treatments. Although the differences between the chemical fertilizer and effluent were significant, they were small and of little biological interest (Table 4).

General

The reason for the reduction in DMI of sheep fed the irrigated hay compared with the non-irrigated hay and the reduction in DMI of sheep fed the hay produced with effluent compared with the chemically fertilized forage is not evident. The major difference in hay composition was in NO₃-N concentration, which was greatest in the non-irrigated hay. Correlation analysis showed that DMI was not correlated with NDF

concentration of the hay ($r < 0.01$; $P = 0.98$; $n = 9$) or with any of the constituent fiber fractions. However, DMI was associated with DMD ($r = 0.62$; $P = 0.08$; $n = 9$), and DMD was well correlated with the digestion of NDF and its fiber constituents ($r = 0.93$ – 0.98 ; $P = 0.03$ to <0.01 ; $n = 9$).

Because animals select leaves over stems or dead material if given the opportunity (Stobbs, 1973), the hay weighback was analyzed for IVTD, CP, and NDF and averaged 525, 113, and 762 g kg⁻¹, respectively, for the irrigated treatments and 525, 119, and 758 g kg⁻¹, respectively, for the non-irrigated control treatment. Selective leaf consumption is generally indicated by decreased concentration in the weighback of IVTD and CP but increased NDF. Subtracting the weighback concentrations from the “as fed” hay concentrations in Table 4 showed differences for the irrigated treatment in IVTD (525–557 g kg⁻¹), CP (114–113 g kg⁻¹), and NDF (762–767 g kg⁻¹) of –32, 1, and –5 g kg⁻¹, respectively. The non-irrigated treatment showed differences in IVTD (525–560 g kg⁻¹), CP (119–119 g kg⁻¹), and

Table 4. Gross energy, in vitro true dry matter disappearance (IVTD), and nutritive value of Coastal bermudagrass hay from commercial N fertilization compared with treated swine effluent delivered by subsurface drip irrigation (oven-dry matter basis).

Spacing	Treatment†		Gross energy MJ kg ⁻¹	IVTD	CP‡	NO ₃ -N	NDF	Fiber fractions‡			
	N source	Irr. rate %						ADF	HEMI	CELL	Lignin
Irrigated											
0.6 m	F	75§ 100¶	19.0 18.9	560 555	116 114	0.95 0.89	769 766	373 373	395 392	308 311	54.1 53.3
	E	75¶ 100¶	18.8 18.8	553 562	110 114	0.83 0.94	766 766	372 367	393 397	310 303	55.8 55.4
1.2 m	F	75# 100††	19.0 19.0	557 550	113 114	0.88 0.79	767 768	375 373	391 393	311 308	53.4 53.7
	E	75¶ 100¶	18.8 18.8	557 558	111 112	0.89 0.94	770 768	371 373	398 394	308 306	54.4 55.6
Non-irrigated	F	none§	18.9	560	119	1.11	765	373	391	309	55.4
Means (irrigated)	All		18.8	557	113	0.89	767	372	394	308	54.5
	F		19.0	556	114	0.87	768	373	393	310	53.6
	E		18.8	558	112	0.90	767	371	395	307	55.3
	75		18.9	557	113	0.89	768	373	394	309	54.4
	100		18.9	557	113	0.89	767	371	394	307	54.5
	SEM		0.1	10	4	0.09	5	4	6	7	1.1
Contrasts, partial orthogonal set (<i>P</i> value)											
Irrigated (I) vs. non-irrigated			0.26	0.55	<0.01	<0.01	0.47	0.55	0.21	0.63	0.23
0.6 m vs. 1.2 m			0.04	0.51	0.55	0.51	0.27	0.10	0.88	0.83	0.47
I F vs. I E			<0.01	0.53	0.08	0.52	0.78	0.03	0.13	<0.01	<0.01
I 75 vs. I 100			0.52	0.94	0.63	0.92	0.35	0.34	0.79	0.02	0.88
Contrasts of interest (<i>P</i> value)											
Non-irrigated vs. I 75			0.09	0.83	0.09	0.01	0.36	0.75	0.46	0.61	0.07
Non-irrigated vs. I 100			0.44	0.24	0.04	<0.01	0.64	0.95	0.57	0.73	0.03

† Spacing is the distance between laterals; If irrigated, either 300 g kg⁻¹ urea-ammonium nitrate solution (F) or treated swine effluent (E); if non-irrigated, topdressed with granular (345 g N kg⁻¹) ammonium nitrate (F). Irr. Rate, irrigation rate applied at 75 or 100% of calculated daily evapotranspiration values.

‡ ADF, acid detergent fiber; CELL, cellulose; CP, crude protein; HEMI, hemicellulose; NDF, neutral detergent fiber.

§ Each value is the mean of 18 animals.

¶ Each value is the mean of 19 animals.

Each value is the mean of 16 animals.

†† Each value is the mean of 17 animals.

NDF (758–765 g kg⁻¹) of –35, 0, and –7 g kg⁻¹, respectively. The decrease in IVTD of the weighback, relative to the “as fed” hay, indicates that some selective consumption of the hays may have occurred and is supported by the lack of correlation between the IVTD of the “as fed” hay and weighback concentrations ($r = 0.29$; $P = 0.45$; $n = 9$). There was no indication that the selective consumption was any greater in the non-irrigated than the irrigated hays.

In a previous study with sheep fed bermudagrass hays of similar age but produced under different environments (water stress and temperature), differences in DMI were noted, and DMI was least for hays grown under more favorable moisture conditions (Burns and Fisher, 2007). This is consistent with accelerated growth due to favorable moisture and temperature conditions (DaSilva et al., 1987; Buxton and Casler, 1993; Buxton and Fales, 1994) and may have been a contributing factor for the greater DMI from the non-irrigated treatment compared with the irrigated treatment in this study. This is, in part, supported by the differences noted in this study between the 75 and 100% irrigation rate. As noted previously, DMI was greater for the 75% rate, as was DMD, NDF digestion, and its constituent fractions and the digestible intakes of all (Table 3). Although irrigation rate differences were not reflected in the

nutritive value estimates of the hay (Table 4), the nature of the dry matter was apparently altered by water application.

Conclusions

Coastal bermudagrass hay produced from swine waste that was processed directly through a waste treatment facility and the liquid fraction delivered via subsurface drip irrigation was readily consumed by wether sheep. Hays produced from chemical fertilizer were consumed in greater amounts compared with subsurface drip irrigation (1.81 vs. 1.71 kg 100 kg⁻¹ BW). Dry matter intake, a measure of hay consumption, was greater for the non-irrigated treatment with chemical fertilizer and averaged 1.94 kg 100 kg⁻¹ BW compared with 1.77 for the irrigated hays. The non-irrigated and irrigated hays were similar in nutritive value, except the non-irrigated hays (at this fertility level) had greater concentrations of NO₃-N and may have health implications if consumed as the sole diet by pregnant ruminants. Among the irrigated treatments, the dry matter intake of the N fertilized hay was greatest and averaged 1.81 kg 100⁻¹ kg BW, compared with 1.71 for hay irrigated with treated effluent. Irrigating at 75% of calculated evapotranspiration increased apparent DMD (527 vs. 508 g kg⁻¹) and NDF digestion (580 vs. 560 g kg⁻¹) of Coastal bermudagrass, and digestion of its

constituent fiber fractions. No differences in animal responses were noted between lateral spacings of 0.6 vs. 1.2 m in the layout of the subsurface drip irrigation system. Raw swine waste treated in a waste treatment system resulted in effluent that could be readily delivered, at recommended N rates by SDI, for the production of hay of acceptable quality for ruminant production systems.

References

- Adeli, A., and J.J. Varco. 2001. Swine lagoon effluent as a source of nitrogen and phosphorus for summer forage grasses. *Agron. J.* 93:1174–1181.
- AOAC. 1990. Official methods of Analysis 15th ed. Assoc. Offic. Anal. Chem., Arlington, VA.
- Burns, J.C., and W.A. Cope. 1974. Nutritive value of crownvetch forage as influenced by structural constituents and phenolic and tannin compounds. *Agron. J.* 66:195–200.
- Burns, J.C., and D.S. Fisher. 2007. Dry matter intake and digestibility of 'Coastal', 'Tifton 44', and 'Tifton 85' bermudagrass hays grown in the U.S. upper South. *Crop Sci.* 47:795–810.
- Burns, J.C., L.D. King, and P.W. Westerman. 1990. Long term swine lagoon effluent application on 'Coastal' bermudagrass: I. Yield, quality and elemental removal. *J. Environ. Qual.* 19:749–756.
- Burns, J.C., K.R. Pond, and D.S. Fisher. 1994. Measurement of intake. p. 494–532. *In* G.C. Fahey Jr (ed.) *In* Forage quality, evaluation and utilization. ASA, CSSA, SSSA, Madison, WI.
- Burns, J.C., P.W. Westerman, L.D. King, G.A. Cummings, M.R. Overcash, and L. Goode. 1985. Swine lagoon effluent applied to 'Coastal' bermudagrass: I. Forage yield, quality, and element removal. *J. Environ. Qual.* 14:9–14.
- Buxton, D.R., and M.D. Casler. 1993. Environmental and genetic effects on cell wall composition and digestibility. p. 685–714. *In* H.G. Jung et al (ed.) *Forage cell wall structure and digestibility*. ASA, CSSA, SSSA, Madison, WI.
- Buxton, D.R., and S.L. Fales. 1994. Plant environment and quality. p. 155–199. *In* G.C. Fahey, Jr (ed.) *Forage quality, evaluation, and utilization*. ASA, CSSA, SSSA, Madison, WI.
- Chamblee, D.S., J.T. Green, Jr., and J.C. Burns. 1995. Principal forages of North Carolina: Adaptation, characteristics, management, and utilization. p. 25–47. *In* D.S. Chamblee and J.T. Green Jr (ed.) *Production and utilization of pasture and forages in North Carolina*. Tech. Bull. 305. North Carolina Agric. Res. Ser., North Carolina State Univ., Raleigh, NC.
- DaSilva, J.H.S., W.L. Johnson, J.C. Burns, and C.E. Anderson. 1987. Growth and environmental effects on anatomy and quality of temperate and subtropical forage grasses. *Crop Sci.* 27:1266–1273.
- Kamphake, L.J., S.A. Hannah, and J.M. Cohen. 1967. Automated analyses for nitrate by hydrazine reduction. *Water Res.* 1:205.
- King, L.D., J.C. Burns, and P. W. Westerman. 1990. Long-term swine lagoon effluent application on 'Coastal' bermudagrass: II. Effect on nutrient accumulation in soil. *J. Environ. Qual.* 19:756–760.
- King, L.D., P.W. Westerman, G.A. Cummings, M.R. Overcash, and J.C. Burns. 1985. Swine lagoon effluent applied to 'Coastal' bermudagrass. II. Effect on soil. *J. Environ. Qual.* 14:14–21.
- Mueller, W., and D.L. Smith. 1991. Compilation of E.P.A.'s sampling and analysis methods. p. 773. *In* L.H. Keith ed. *Nitrogen, nitrate-nitrogen method 353.1*. CRC Press, Boca Raton, FL.
- Murphy, L.S., and G.E. Smith. 1967. Nitrate accumulation in forage crops. *Agron. J.* 59:171–174.
- Norum, E.M., L.U-kosaramig, and R. Ruskin. 2001. Reuse of dairy lagoon wastewater through SDI in forage crops. ASAE paper no. 012266. ASAE, St. Joseph, MI.
- NRC. 1985. Nutrient Requirements of Sheep. 6th ed. National Academy Press, Washington, DC.
- Parson, G.S. 1974. Nitrate poisoning. Dairy handbook. D-13. North Carolina Agric. Ext. Serv., Raleigh, NC.
- SAS Institute Inc. 2004. SAS/STAT 9.1 user's guide. SAS Inst., Cary, NC.
- Stobbs, T.H. 1973. The effect of plant structure on the intake of tropical pastures. I. Variation in the bite size of grazing cattle. *Aust. J. Agric. Res.* 24:809–819.
- Stone, K.C., P.G. Hunt, J.A. Millen, M.M. Johnson, T.A. Matheny, M.B. Vanotti, and J.C. Burns. 2008. Forage subsurface drip irrigation using treated swine wastewater. *Trans. ASABE* 51:433–440.
- Suarez-Rey, E., C.Y. Choi, P.M. Waller, and D.M. Kopeck. 2000. Comparison of subsurface drip irrigation and sprinkler irrigation for bermudagrass turf in Arizona. *Trans. ASABE* 43:631–640.
- Sutton, A.L., D.W. Nelson, J.D. Hoff, and V.B. Mayrose. 1982. Effects of injection and surface application of swine manure on corn yield and soil composition. *J. Environ. Qual.* 11:468–472.
- Vanotti, M.B., and A.A. Szogi. 2008. Water quality improvements of wastewater from confined animal feeding operations after advanced treatment. *J. Environ. Qual.* 37:S86–S96.
- Vanotti, M.B., A.A. Szogi, P.G. Hunt, P.D. Miller, and F.J. Humenik. 2007. Development of environmentally superior treatment system to replace swine waste lagoons in the USA. *Bioresour. Technol.* 98:3184–3194.
- Van Soest, P.J., and J.B. Robertson. 1980. Systems of analysis for evaluating fibrous feeds. p. 49–60. *In* W.J. Pigden et al (ed.) *Standardization of analytical methodology for feeds*. International Development Res. Center, Ottawa, ON, Canada.
- Westerman, P.W., M.R. Overcash, R.O. Evans, L.D. King, J.C. Burns, and G.A. Cummings. 1985. Swine lagoon effluent applied to 'Coastal' bermudagrass: III. Irrigation and rainfall runoff. *J. Environ. Qual.* 14:22–25.
- Whitaker, J.R., G.L. Ritchie, C.W. Bednarz, and C.I. Mills. 2008. Cotton subsurface drip and overhead irrigation efficiency, maturity, yield and quality. *Agron. J.* 100:1763–1768.
- Woodhouse, W.W., Jr. 1969. Long-term fertility requirements of Coastal: II. Nitrogen, phosphorus, and lime. *Agron. J.* 61:251–256.