An Environmental Comparison of Two Year-round Forage Systems Under Dairy Effluent Irrigation in the Suwannee River Area

K. R. Woodard, L. E. Sollenberger, E. C. French, L. A. Sweat,
B. Macoon, D. A. Graetz, and H. H. Van Horn

Summary

Florida dairies need productive, year-round forage systems that prevent loss of N to groundwater from waste effluent sprayfields. Our purpose was to measure forage N removal and nitrate-N leaching out of the rooting zone for two, year-round forage systems during four, 12-month cycles. Soil at the site is an excessively drained, Kershaw fine sand. The average annual loading rates of effluent N were 450, 610, and 810 lb/acre per cycle. During the first three cycles, average N removed by the bermudagrass-rye cropping system (BR) was 415, 472, and 522 lb/acre per cycle for the low, medium, and high loading rates, respectively. For the corn-forage sorghum-rye system (CSR), N removals were 286, 292, and 338 lb/acre per cycle, respectively. The higher N removals of the BR system were attributed to higher N concentration in bermudagrass (range: 1.9 to 2.2 %) compared to that in corn and forage sorghum (range: 1.1 to 1.3 %) of the CSR system. Nitrogen removal by the rye components of both systems did not differ. Over the four-cycle period, N removal for rye ranged from 48 to 78 lb/acre per cycle. Dry matter yield declined in the fourth cycle for bermudagrass but N removal continued to be higher in BR than CSR. The BR system was much more effective at preventing nitrate-N leaching. For CSR, nitrate-N concentration in soil water (five feet below surface) increased steeply during the period between the harvest of one forage and canopy closure of the next, peaking within a few days of canopy closure and subsequently declining. We conclude that the BR system was better than CSR at preventing nitrate-N loss to groundwater in dairy effluent sprayfields.

Introduction

There has been a growing concern over the potential environmental impact of the increasing number and size of dairy operations in watersheds surrounding the historic Suwannee River in North Florida. According to 2000 inventory estimates, the combined total number of milk cows within four of the eight Florida counties that border the Suwannee River accounts for 27% of the state's 156,000 head (FASS, 1999). Many of the upland soils within Suwannee River watersheds are excessively-drained, deep, sandy Entisols with low organic matter, mineral concentrations, and cation exchange capacity. These soil characteristics coupled with relatively high annual rainfall and periodic heavy and intense rainfall events, increase the possibility that nitrate-N will leach through the soil profile and contaminate groundwater.

Dairy managers in North Florida recognize that manure effluent is a viable resource for plant nutrients and are involved in the year-round production of forage crops in effluent

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K. R. Woodard, L. E. Sollenberger, E. C. French (deceased), L. A. Sweat, and B. Macoon, Agronomy Dep., D. A. Graetz, Soil and Water Science Dep., and H. H. Van Horn, Jr., Animal Sciences Dep., Univ. of Florida, IFAS, Gainesville, FL 32611.

sprayfields. Forage crops remove large quantities of nutrients from the soil because nearly all aboveground biomass is removed during harvest in contrast to grain production systems. In most cases, the harvested forage containing recycled dairy effluent minerals can be utilized on-farm, thereby reducing nutrient imports.

The following project was funded by a grant from the Florida Department of Environmental Protection, Tallahassee. Five, year-round forage systems were evaluated under dairy effluent irrigation over four, 12-month cycles and with three annual loading rates of effluent N. Results from two of the forage systems will be reported. Our objectives were (i) to measure the capacity of forage components as well as year-round systems for removing N from the soil and preventing it from leaching below the rooting zone and (ii) to identify periods within a cropping cycle that are particularly vulnerable to nitrate-N leaching and determine causal factors.

Methods

The project was conducted in a dairy effluent sprayfield owned by North Florida Holsteins, Inc., near Bell, Florida. Soil in the sprayfield is an excessively drained, deep sand with low nutrient- and water-holding capacities (Weatherspoon et al., 1992). The average date (50% probability) of first freeze for the area is 25 November, while the average date of last freeze is 10 March (Bradley, 1983).

Mainplot treatments consisted of low, medium, and high effluent N loading rates applied over a 12-month cycle. The project continued for four, 12-month cycles with the first starting in April 1996 and the last ending in March 2000. The average low, medium, and high N loading rates during the four cycles were 450, 610, and 810 lb/acre per cycle, respectively. The irrigation system used to apply the dairy effluent was a five-tower Rainbow center pivot, retrofitted with a series of sprinklers and ball valves (Fig. 1). Nests of Nelson P85A part-circle, impact sprinklers (Nelson Irrigation Corporation, Walla Walla, WA) were installed on platforms built on the support beams of the pivot in the areas corresponding to the center of the mainplots. Sprinklers within a group were vertically offset to avoid contact between sprinkler streams. They were adjusted to deliver one stream of water, set at an 140° arc, and centered over the mainplots. Bypass sprinklers were installed on "nonplot" sections of the pivot to maintain constant water pressure during effluent irrigations that excluded appropriate mainplots.

During the four 12-month cycles, the average number of effluent applications per cycle to achieve the high N rate was 22. Low- and medium-N rate mainplots received effluent on 50 and 75% of the irrigations, respectively. When mainplots did not receive effluent, they were irrigated with an equal volume of freshwater within a 3-day period. Overall supplemental freshwater irrigations were applied during dry times to reduce crop stress; however, crops were subjected to a moderate degree of moisture stress similar to that occurring in a production enterprise. To aid in application uniformity, effluent irrigations and the majority of freshwater applications occurred at night when wind speeds were less than five miles per hour. A typical irrigation resulted in 0.65 inches of water being applied to the soil surface.

A mainplot was divided into five, 50 x 50 ft subplots. A subplot was randomly assigned one of five, 12-month forage systems. Results will be shown for two systems, (i) bermudagrass-rye and (ii) corn-forage sorghum-rye. The bermudagrass was 'Tifton 85', developed in Georgia (Burton et al., 1993; Burton, 2001). Annual crops included 'Northrup King 508' corn, 'Dekalb FS25E' forage sorghum, and 'Wrens Abruzzi' rye. Annual forages were established using no-till

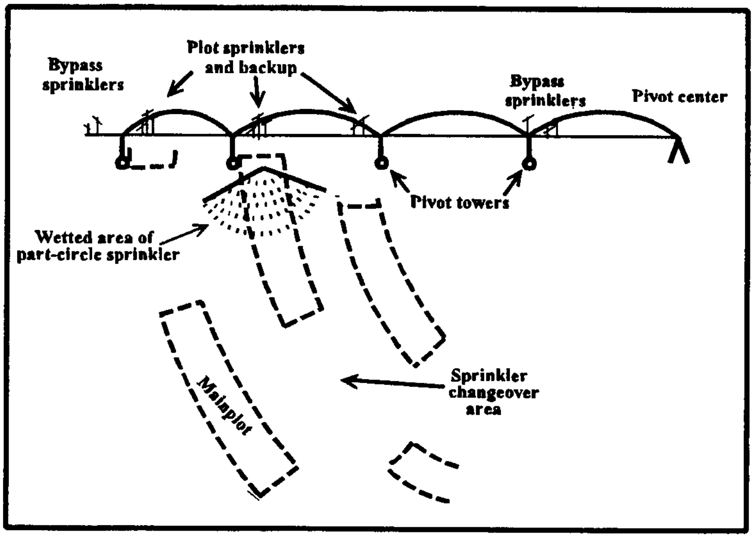

Fig. 1. Design used for mainplot layout in the dairy effluent sprayfield.

planting equipment. Planting dates for corn were between 29 March and 4 April each year, for forage sorghum between 31 July and 14 August, and for rye between 24 November and 8 December. The corn was harvested in the early dent stage of kernel development when dry matter concentration in the above-ground biomass was 30% or above, a level generally required for good ensiling. Forage sorghum was harvested at the stiff-dough stage. Rye was harvested at full seedhead emergence. The bermudagrass was harvested four to five times during the warm season (April to October). Treatments were replicated three times.

To sample soil moisture below the primary rooting zone, suction lysimeters were constructed by attaching a ceramic cup to the end of a two-inch PVC pipe. The pipe was cut to the appropriate length so that after installation, the ceramic cup was five feet below the soil surface. Two lysimeters were installed in each subplot. Sampling began in July 1996 and continued through March 2000 at near 14-day intervals.

Solution samples from the lysimeters were analyzed for nitrate-N concentration. Dairy effluent samples were analyzed for total-, ammonia-, and nitrate-N concentrations. Forage samples were analyzed for total-N concentration using the standard Kjeldahl procedure. The project was conducted using the standard operating procedures required by Florida Department of Environmental Protection (FDEP, 1992).

Results and Discussion

Yield, Nitrogen Percentage, and Nitrogen Removal

Nitrogen removal for the BR system was superior to that of the CSR system in all four 12-month cycles (Table 1). Nitrogen removal for the CSR system was quite stable over the four cycles whereas it varied with the BR system with the highest average computed for the second cycle and the lowest for the fourth. Over the first three cycles, the BR system removed an

Table 1. Annual N removal for the bermudagrass-rye (BR) and corn-forage sorghum-rye (CSR) systems at low, medium, and high effluent N loading rates during four, 12- month cycles near Bell, Florida.

	BR				CSR			
Cycle†	Low	Med	High	Avg‡	Low	Med	High	Avg‡
	lb/acre							
1996-97	412	402	458	424b§	296	293	328	306a§
1997-98	457	559	597	538a	267	281	329	292a
1998-99	377	454	512	448b	296	303	356	318a
1999-00	342	389	388	373c	271	302	325	299a

† The average loading rates per 12-month cycle were 450, 610, and 810 lb/acre of effluent N for the low, medium, and high levels, respectively.

‡ The average N removal within each of the four, 12-month cycles for the BR system was higher than that of the CSR system ($p < 0.001$).

§ Means within a column followed by the same lowercase letter are not different ($p > 0.05$).

average of near 180 lb/acre more N than CSR at the medium and high loading rates but in the fourth cycle it removed 75 lb more N. To explain these results, the performance of the individual forages must be examined since the quantity of N removed by a cropping system is mainly determined by the (i) forage components making up the system, (ii) weight of the dry biomass removed during harvest, and (iii) N percentage in the harvested biomass.

Warm- and Cool-Season Components. For rye, the cool-season component, dry matter yield, forage N percentage, and N removal did not differ between systems (Table 2). Therefore, the differences in N removal between the BR and CSR systems were attributable to the performance of warm-season components. Bermudagrass was harvested multiple times during the 200- to 220-day warm season that generally begins in early April and continues through late October. This period coincides with the sequential growing seasons for corn followed by forage sorghum, thereby allowing for direct comparisons with full-season bermudagrass. Nitrogen removal was greater for bermudagrass than corn plus sorghum in all four cycles (Tables 3 and 4). The magnitude of the difference between bermudagrass and corn plus sorghum was almost identical to that between the BR and CSR systems. Though N removal of the corn plus sorghum was lower, it remained quite stable during the four 12-month cycles, a consequence of stable yields and forage N percentages. The major reason for greater removals in the first three cycles was the higher N percentage found in bermudagrass (range; 1.9 to 2.2 %) than in corn and forage sorghum (range; 1.1 to 1.3 %) and not higher yield (Table 3). Nitrogen removal by the bermudagrass was substantially lower in the fourth cycle than in previous cycles because of a reduction in yield, primary in plots receiving the higher loading rates (Table 4). The lower yields were primarily caused by reductions in bermudagrass stand in plots receiving the higher loading rates. Visual estimates of bermudagrass ground coverage on 28 May 1999 (just before the first

Table 2. Average dry matter yield, N percentage, and N removal for rye in the bermudagrass-rye (BR) and corn-forage sorghum-rye (CSR) systems over four, 12-month cycles and evaluated under dairy effluent irrigation near Bell, FL.

Effluent N loading rate	Rye (BR)			Rye (CSR)		
	Yield	N†	N remov.	Yield	N†	N remov.
lb/acre/cycle	ton/acre	%	lb/acre	ton/acre	%	lb/acre
450	1.5	1.6	48	1.6	1.6	50
610	1.8	1.9	67	1.7	1.8	60
810	1.9	2.0	72	2.0	2.0	78

† To compute crude protein percentage in dry matter multiply averages by 6.25.

Table 3. Average dry matter yield, N percentage, and N removal for bermudagrass (BR system) and corn and forage sorghum (CSR system) over three, 12-month cycles (1996-97, 1997-98, 1998-99), evaluated under dairy effluent irrigation near Bell, FL.

Effluent N loading rate	Yield		N percentage†			N removal	
	Bermuda	C plus S	Berm.	Corn	Sorg.	Bermuda	C plus S
lb/acre/cycle	----- ton/acre -----		----------- % -----------			------ lb/acre -------	
450	9.7	10.3	1.9	1.1	1.2	368	236
620	9.9	9.3	2.0	1.2	1.3	406	230
820	10.5	10.3	2.2	1.3	1.3	452	263

† To compute crude protein percentage in dry matter multiply average by 6.25.

harvest) were 97, 89, and 80% in plots receiving the low, medium, and high loading rates, respectively. The reduction in yield from the third to the fourth cycle was 1.0, 1.3, and 2.8 tons/acre for the low, medium, and high loading rates. Throughout the 1999 warm season, goosegrass, a summer grass common to dairy sprayfields in the area, began to appear in weakened parts of the bermudagrass sward in the medium and high rate plots. For perennial grasses in general, high rates of N fertilization tends to decrease carbohydrate reserves (White, 1973) and increase the likelihood of winterkill (West and Prine, 1973). Tifton 85 bermudagrass may have a predisposition to winterkill. It has fewer rhizomes than 'Coastal' and 'Tifton 44' bermudagrasses (Burton et al., 1993).

<u>Effect of Effluent N Loading Rate.</u> Forage N percentage increased as loading rate increased for bermudagrass and rye but not for corn and forage sorghum, though in all cycles average percentages for corn and sorghum at the low loading rate were numerically lower than those of the medium and high rates, which suggests a slight influence of rate. Loading rate had

Table 4. Average dry matter yield, N percentage, and N removal for bermudagrass (BR system) and corn and forage sorghum (CSR system) from the fourth, 12-month cycle (1999-2000), evaluated under dairy effluent irrigation near Bell, FL.

Effluent N loading rate	Yield		N percentage†			N removal	
	Bermuda	C plus S	Berm.	Corn	Sorg.	Bermuda	C plus S
lb/acre/cycle	------- ton/acre -------		---------- % ----------			------ lb/acre -------	
430	7.5 (8.5)‡	10.2	1.9	1.1	1.1	292	221
590	7.5 (8.8)	10.0	2.1	1.2	1.3	316	248
800	6.5 (9.3)	9.0	2.4	1.4	1.2	313	234

† To compute crude protein percentage in dry matter multiply averages by 6.25.

‡ Means in parentheses are bermudagrass dry matter yields from the 1998-1999 cycle.

both a positive and negative effect on dry matter yield of bermudagrass. If bermudagrass stands were healthy (as in the first three 12-month cycles) then yield generally increased with loading rate (Table 3). However in the fourth cycle, loading rate had a negative influence on yield because of the loss of stand in plots receiving the higher loading rates (Table 4). Yield of corn and forage sorghum was not affected by loading rate. Rye yield tended to increase with increase in loading rate (Table 2). Loading rate affected N removal of bermudagrass greatly when both yield and N percentage increased with rate (1997-98 and 1998-99; Table 1). With corn and forage sorghum, loading rate generally had little effect on N removal because yield and N percentage did not increase with rate. For rye, N removal mostly increased because N percentage increased with rate coupled with the tendency for yield to increase.

Ideal Crop for N removal. The ideal crop for long term N removal in dairy sprayfields produces high yields, has a high forage N percentage, luxury consumes N with increasing loading rate, and can maintain a high level of crop performance over several years. Of the four forage components of the two systems, bermudagrass was the closest to possessing these attributes. For the first three 12-month cycles, it maintained a high level of performance. It produced high yield and had moderately high N percentage which increased with loading rate. Its shortcoming, however, was the reduction in yield in the fourth cycle due to the reduction in stand that occurred with the higher loading rates.

The corn plus forage sorghum combination produced stable yields over the four-year period, but its major shortcoming was low N percentage. Rye had moderately high N percentage which increased with loading rate but dry matter yield was low (Table 2), considering the portion of a 12-month cycle taken up by this forage (about 100 days).

Nitrate Nitrogen Leaching Patterns

The BR system was superior to CSR at preventing nitrate-N from leaching below the primary rooting zone (Fig. 2) . Throughout the 1997-98 cycle, average nitrate-N concentrations for the BR system were mostly below 10 mg/L (or 10 parts per million) for the low and medium

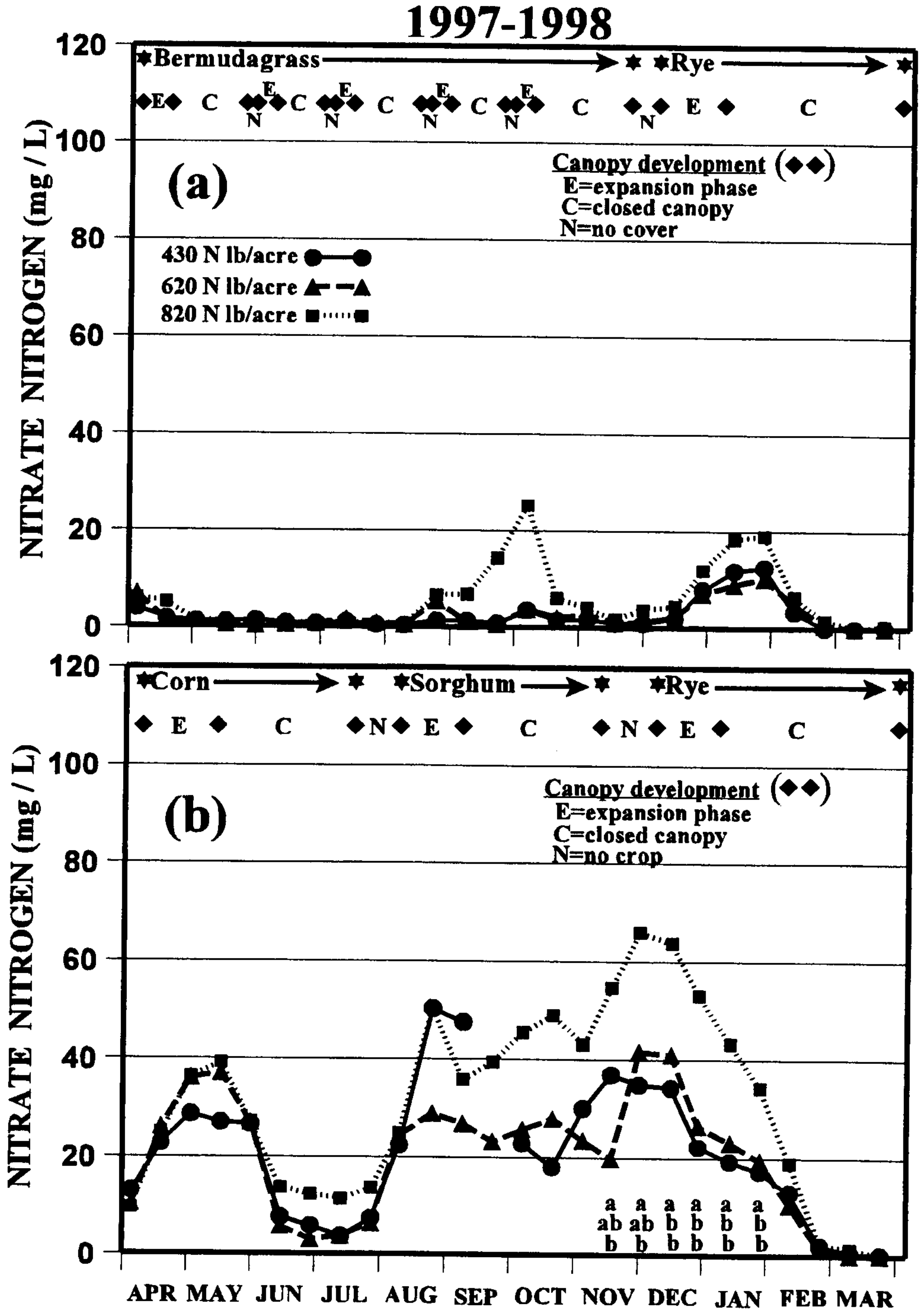

Fig. 2. Nitrate-N concentration (mg/L equals parts per million) in soil water extracted from five feet below the surface for the bermudagrass-rye (a) and corn-forage sorghum-rye (b) systems at three dairy effluent N loading rates during the second, 12-month cycle (1997-1998) near Bell, Florida. Means within sampling date followed by the same corresponding lowercase letter are not different (p > 0.10).

loading rates. For the high rate, mean concentration exceeded 20 mg/L on one sampling date in early October. After the last bermudagrass harvest in November, concentrations increased for the three loading rates through January but did not exceed 20 mg/L. From there, levels declined to near zero during February. The low levels were maintained through March.

In the CSR system, greater nitrate-N concentrations were measured throughout most of the 1997-98 cycle (Fig. 2b). Growth phases of the annual forage components had a strong influence on leaching patterns. Following rye harvest in March 1997, mean concentrations increased during the no-crop period (harvest of one crop to seedling emergence of the next) and the canopy expansion phase (seedling emergence to complete canopy closure) of the corn. The highest peaks ranged between 20 and 40 mg/L for the three loading rates and corresponded to the time when canopy closure occurred. Mean nitrate-N concentrations decreased to levels at or below 10 mg/L during the closed-canopy period of the corn. After corn harvest in mid-July of 1997, nitrate-N levels began to increase over the no-crop period and sorghum expansion phase. For the low N loading rate, concentration declined during the closed-canopy period of the sorghum. For the medium and high rates, the peak concentrations declined slightly or were maintained during that period. Then nitrate-N concentrations began to increase at or just prior to sorghum harvest to peaks near 40 mg/L for the low and medium rates and over 60 mg/L for the high. From there, levels steeply declined during the expansion phase and first half of the closed-canopy phase of the rye to near zero in late February 1998 for all rates. The low concentrations were maintained through March.

The "roller coaster" pattern of rising and falling nitrate-N concentrations observed in the CSR system is likely a distinctive feature of cropping systems made up of sequentially planted annual forages. The period between the harvest of one annual crop and full canopy closure of the next crop is highly prone to nitrate-N leaching for a number of reasons. During the no-crop period, uptake of N and soil water drops to near zero and is minimal during the canopy expansion phase of the next crop, especially during early seedling development. Secondly, effluent irrigation generally continues in dairy sprayfields during transition periods adding more N and water to the upper profile. With limited uptake, soil water movement into the lower soil profile can increase, carrying nitrate-N out of the rooting zone. Thirdly, excess N not utilized by the previous crop may be present in the upper profile at harvest. During the closed-canopy period of the previous forage, soil moisture in the rooting zone is continuously being depleted. This would impede unutilized N from leaching out of the upper profile. Finally, the transition period between annual forages lasts several weeks which increases the possibility that heavy rainfall events will occur. Estimated transition periods (no-crop period plus expansion phase) between the forage components of the CSR system ranged from 48 to 61 days. Avoiding delays between harvest and the planting of the next annual crop will shorten transition periods but little can be done to shorten the time required for seedling emergence and the development of a closed canopy and extensive root system.

The BR system was superior to the CSR system because of its highly productive perennial sod that was harvested several times during the warm-growing season. The bermudagrass component not only removed more N from the soil than its corn plus sorghum counterpart, but N uptake and soil moisture usage were more continuous over the season. This provided less opportunity for buildup and major leaching events to occur. The periods between closed-canopy phases of bermudagrass were much shorter than the transition periods between annual crops. These periods were segmented into "no-cover" periods and expansion phases (Fig. 2a). After harvest, the stolon-rhizome-root system remains intact and new shoots generally emerge within five days. During the short no-cover period, the uptake of N and soil moisture was likely reduced but does not drop to near zero as with the no-crop periods of the CSR system. Also, the expansion phase was much shorter because the stolon-rhizome-root system allowed for rapid canopy development.

Leaching Patterns during the Growth Period of Winter Rye. The sharp reduction in lysimeter nitrate-N concentration during the closed-canopy period of rye in the CSR system, suggested that large amounts of N as well as soil moisture were being extracted from the soil (Fig. 2b). This outcome was inconsistent with the low N removal measured for the rye (Table 2). Though nitrate-N levels should marginally decline during the closed-canopy period of rye, the magnitude of the rate of decline that was observed may be in part due to the reduction in the rate of microbial conversion of effluent-N to nitrate-N during the winter months. Dairy effluent had two primary forms of N. Approximately one third of effluent-N was in organic form while the remainder was ammoniacal-N. Soil microbes convert these forms into nitrate-N and the rate of conversion is dependent on temperature.

It is possible that the near constant year-round surface loading of effluent N in dairy sprayfields may not result in a corresponding constant load of nitrate-N in the rooting zone because of the effect of seasonal temperatures on the microbial processes that convert effluent-N to nitrate-N (Das et al., 1995; Dou et al., 1997). If the nitrate-N load in the upper profile increases during the warm months and declines during the cool months (Fig. 3), then to control leaching year-round, warm-season forages would be required to remove more N from the soil relative to the amounts of effluent-N applied to the soil surface during their growth periods. Conversely, less would be required of cool-season forages. Evidence that nitrate-N load in the root zone varies with seasonal temperatures include the steep declines in nitrate-N concentration to low levels following very high peaks during early rye growth in the CSR system (Fig. 2b) and the low nitrate-N levels that were somewhat maintained during the rye growth period of the BR system (Fig. 2a). If the degree of nitrate-N availability in the topsoil over a 12-mo cycle parallels the near constant loading of effluent N on the soil surface, then with the low forage N removal of the rye observed in both systems, much higher nitrate-N concentrations should have been measured during the closed-canopy phase of the rye.

The optimal temperatures for maximum rates of conversion from effluent-N to nitrate-N in the soil correspond to maximum rates of dry matter accumulation and N uptake by warm-season grasses. In addition, daily crop growth rates are potentially much higher during the summer months because of the increase in daily solar radiation (Fig. 3). Conversely, a limiting factor for yield of cool-season forages is reduced incoming solar radiation during the winter months. We suggest that the bermudagrass in the BR system compensated for the poor performance of winter rye by removing large quantities of N from the soil during the warm season, thereby minimizing residual nitrate-N following the last bermudagrass harvest. [At the high loading rate, the bermudagrass removed an average of 452 lb/acre of N during the first three 12-mo cropping cycles, compared to a mean of 72 lb/acre of N by the rye component.]

Though the corn and forage sorghum components of the CSR system are productive grasses, they failed to remove the necessary quantities of N from the soil. [At the high loading rate, the 4-year mean N removal for corn plus forage sorghum was 256 lb/acre.] As a result, considerable nitrate-N moved out of the rooting zone during the warm season and large amounts of residual nitrate-N were apparently present in the upper profile at harvest of the sorghum,

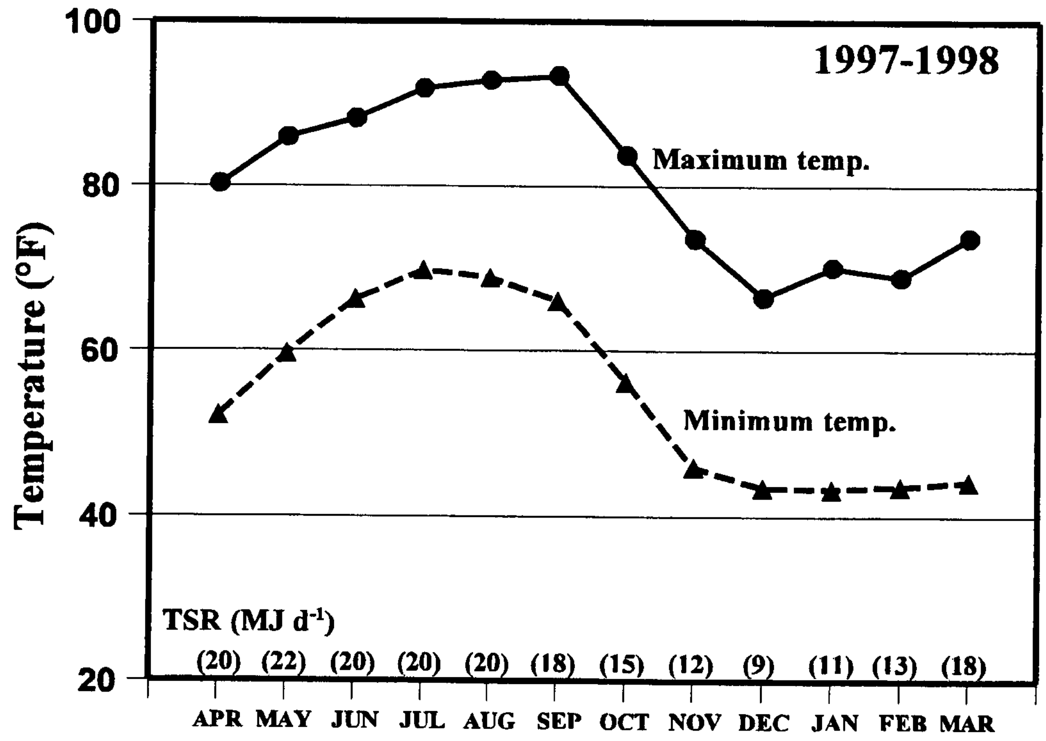

Fig. 3. Monthly average maximum and minimum temperatures and daily total solar radiation (TSR; means in parentheses) recorded at the project site near Bell, Florida during the 1997-1998 cropping cycle.

resulting in high nitrate-N peak concentrations during the early growth of rye. Our explanation for the steep decline in nitrate-N concentration to very low levels during the closed-canopy period of rye is that the wave of residual nitrate-N moved through the soil profile during the first half of winter, a time when nitrate-N buildup in the topsoil was low because lower temperatures reduced the rate of conversion from effluent-N to nitrate-N. Low nitrate-N levels were maintained in lysimeter soil water samples for the remainder of the closed-canopy period of the rye because plant N uptake was adequate for the reduced amounts of nitrate-N becoming available in the rooting zone.

Conclusions

The BR system was superior to the CSR system because it removed more N from the soil and maintained lower nitrate-N concentrations below the primary rooting zone. The performance of the rye component did not differ between systems, therefore the effectiveness of the systems was determined by the warm-season forages. Bermudagrass removed more N from the soil than the corn and sorghum combination, mainly because it had higher forage N percentage and not higher dry matter yield. In the CSR system, the period between harvest of one forage and canopy closure of the next was identified as being highly prone to nitrate-N leaching due to the time required for seedling emergence and development. These findings suggest that year-round forage systems which include a perennial, warm-season grass are better than those made up entirely of annual forages at preventing nitrate-N loss to groundwater in Suwannee River watersheds.

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