POTENTIAL IMPACT OF CLIMATE VARIBILITY ON NITROGEN LEACHING IN NORTH FLORIDA DAIRY FARMS

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Abstract

Nitrogen leaching on a dairy farm depends on their forage systems, manure N produced, seasonal climatic conditions, soil characteristics, and various livestock and manure management practices. The purpose of this paper was to study the variability in N leaching due to climate variability in north Florida dairy farms. Since N leaching in dairy farms is impacted by climate patterns, seasonal forecasts can be used to predict it. The Decision Support System for Agrotechnology Transfer (DSSAT) was used to predict N leaching and biomass accumulation after being calibrated and validated for specific crops and soils. All eleven forage systems common in North Florida were simulated over 43 years using daily weather data, for all levels of manure N applied (20-160 kg N ha^{-1} month^{-1}), and for all ten soil types where dairies are located. Nitrogen leaching and crop biomass accumulation were summarized for different climatic years. Simulated results indicated that higher N leaching and lower biomass accumulation occurred in El Niño years relative to neutral and La Niña years. Winter in general, and January and February specifically, were critical for N leaching, in all ENSO phases. The best forage systems to prevent N leaching were those that start in spring-summer with bermudagrass or maize; had bermudagrass, bahiagrass or maize in summer; and finished with winter forages. Systems that leached the most were those that included millet and/or sorghum.

1 Introduction

The presence of high N levels in water is an environmental hazard because it affects human health and ecosystem welfare. The Suwannee River Basin has received much attention in recent years because of increased N levels in water bodies. Dairy waste may be an important factor contributing to this problem. Dairy farmers are now required to comply with more strict environmental regulations either through permits or voluntary incentive-based programs. The main way farms have to reduce their total N loads is through forage crop systems that are able to recycle a large part of N produced on the farm. Improvements in seasonal climate predictions (lead times of 6 to 12 months) may be useful in devising management strategies that dairy farmers in north Florida could adopt to attain economic and ecological sustainability.

Although exporting manure off the farm is an option, few farms use this practice, typically for a small part of their waste. Dairy farmers must deal with their manure on the farm. Manure is applied to fields through spraying and/or through direct animal deposition. The amount of N in manure is usually high compared with inorganic fertilization applications. Therefore, crops need to absorb as much N as possible to prevent environmental problems.

A few studies have evaluated manure N uptake and loss in forage systems of dairy farms. In Georgia, Hubbard et al. (1987) found concentrations between 10 to 50 mg L^{-1} of NO_3-N at 2.4 m below the soil surface in a forage system of bermudagrass (*Cynodon* spp) and ryegrass (*Lolium multiflorum*) when 530 to 1080 kg ha^{-1} of N in dairy effluents were applied. Johnson et al. (1991) presented data indicating that bermudagrass takes up between 107 and 130 kg N ha^{-1}, rye (*Secale cereale* L.) between 140 and 250 kg N ha^{-1}, and maize (*Zea mays* L.) between 178 and 237 kg N ha^{-1}, when applied rates of manure N were between 385 and 1,000 kg N ha^{-1}. Vellidis et al. (1993) found N concentrations between 0 and 14 and between 4 and 21 mg L^{-1} in a system of bermudagrass-rye applied with 400 and 800 kg ha^{-1}, respectively. A follow up study, reported by Newton et al. (1995), found that N uptake by maize, bermudagrass, and rye was 86, 143, and 91 kg ha^{-1}, with application of 400 kg N ha^{-1}, and 157, 137, and 169 kg ha^{-1} with application of 800 kg N ha^{-1}.

For north Florida conditions, French et al. (1995), presented in Van Horn et al. (1998), found that a crop sequence of perennial peanut (*Arachis glabrata* Benth.) and rye absorbed 430, 470, and 485 kg N ha^{-1} $year^{-1}$ receiving 400, 455, and 500 kg N ha^{-1} $year^{-1}$ from manure effluent, respectively. The rye forage in this system accumulated 4, 4.7, and 4.5 Mg ha^{-1} of dry matter containing 60, 80, and 92 kg of N, respectively.

Woodard et al. (2002) performed an extensive experiment for four years (1996-2000) on a north Florida dairy with forage systems growing under different rates of effluent application (500, 690, and 910 kg N $ha^{-1}year^{-1}$). The accumulated dry biomass was (Mg ha^{-1}) 20.5, 20.9, and 21.2 for bermudagrass, 13.4, 12.6, and 12.8 for maize, 9.6, 8.7, 9.4 ha^{-1}, for sorghum (*Sorghum bicolor* L.), and 3.4, 3.9, and 4.4 for rye. N removal of these forages was (kg N ha^{-1}) 390, 430, and 467 for bermudagrass, 148, 152, 166 for maize, 111, 111, and 120 for sorghum, and 55, 70 and 85 for rye. The rye was in both a bermudagrass-rye system and a maize-sorghum-rye system and it performed similarly in both. For this experiment, lysimeters were installed 1.5 m below the surface and measurements were made every 14 days. In the bermudagrass-rye system, NO_3-N levels never exceeded 10 mg L^{-1} during the time bermudagrass was growing (April-November) but went above 30 mg L^{-1} during the time of the rye (December-March). For the maize-sorghum-rye system, NO_3-N were much higher. They reached levels of 20 to 40 mg L^{-1} during maize growth

(April-July), 20 to 60 mg L^{-1} during sorghum growth (August-November), and 30 to 60 mg L^{-1} during rye growth (December-March).

The use of ENSO-based forecast can reduce N leaching in north Florida dairy farms. The goal of the present study was to assess potential N leaching from forage systems under intensive application of dairy manure in North Florida. The specific objectives were to estimate: 1) the capacity of north Florida forage systems to accumulate biomass and remove N from the soil and 2) the risk of N leaching under different conditions of: a) seasonal climate variation, b) crop systems, c) soil types, d) waste management systems, and e) manure N applications.

2 Materials and Methods

2.1 Site Description

The study was conducted on dairies in Suwannee, Lafayette, Gilchrist, Levy, and Alachua counties in the Suwannee River Basin (21.30 to 30.37 N, and 82.43 to 83.35 W) (Figure 1). There were 64 dairy farms in the study area: 25 in Lafayette, 19 in Suwannee, 7 in Gilchrist, 7 in Levy, and 6 in Alachua. These were located using the land use survey (1995) of the Suwannee River Water Management District, contained in the Florida Geographic Data Library (1995).

The soils for each of the farms were located overlaying it on the soil series maps from the Soil Survey Geographic Database (SSURGO) from the Natural Resource Conservation Service (2002). Figure 1 and Table 1 present the soils of the dairy farm systems studied.

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The 10 soil types are summarized in Table 1. For more information, there is a reference to the specific soil survey publication. Datasets consisting of several layers of data for each soil type were collected and organized. These data were converted to the format needed by the DSSAT v4.0 system, using SBuild ® software (Uryasev et al., 2003), where the soil water holding limits were estimated using the Saxton et al. (1986) method.

Daily weather data were obtained for Levy County (29.42 N, 82.82 W), located in the central south part of the Suwannee River Basin, between the years 1956 and 1998 from Mavromatis et al. (2002). During this time, 11 years were classified as El Niño, 10 as La Niña and 23 as neutral. Each El Niño, La Niña, or neutral year begins in October and runs through September of the next calendar year according to the Japan Meteorological Index (JMI) of sea surface temperature (O'Brien et al., 1999). Daily rainfall, minimum and maximum temperature, and solar radiation between October 1st (day 274 (275 for leap years)) and September 30th of the next year (day 273 (274 for leap years)) were categorized into different ENSO years (Figure 2). The DSSAT v4.0 crop models were fed with daily information of these four weather variables during the 43 years (1956-1998).

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2.2 Survey, Focus Groups, and Additional Information

A sample of 21 dairy farmers (30% of the population) participated in the interviews. This sample was obtained in cooperation with the Suwannee Partnership and the University of Florida Cooperative Extension offices in the study area. It was intended to cover the variability in north Florida dairy farm systems with respect to soils, forage systems and management. Interviews were conversational in nature without an instrument, but with a guideline of topics. Interviews lasted between one and two hours and on several occasions, a tour of the farm followed. Conversations were recorded, transcribed, and classified. More general information was obtained by eight focus groups conducted with farmers and other stakeholders such as extension agents, personnel from government and regulatory agencies, and private consultants. Interviews and focus groups were conducted during summer and fall of 2003. Additional secondary information was also obtained from published studies, dairy farm records, and official records.

2.3 Forage Crop Systems

Interviews and focus groups served to identify and understand forage systems used on north Florida dairy farms, including fodder plans, management practices, and sequences. Forage crop simulations were performed using adapted crop models in the Decision Support System for Agrotechnology Transfer, DSSAT v4.0 (Jones et al., 2003). These dynamic crop models simulate crop growth and yield in response to management, climate, and soil conditions. They include light interception, photosynthesis, N uptake, soil water balance, evapotranspiration, respiration, leaf area extension, growth of component parts, root growth, senescence, N mobilization, and crop development processes. For the soil C and N components, the Century model (Parton et al., 1979) implemented in DSSAT by Gijsman et al. (2002) was used. This model estimates soil N balances that include soil and surface organic matter, inorganic N, additions and removals of N, and all the processes that include the N cycle in the soil, such as decomposition, mineralization, N leaching, etc.

Bahiagrass (*Paspalum notatum*) and bermudagrass (Rymph, 2004) are the only forage crops developed for the DSSAT system, therefore, part of the study consisted in adapting, calibrating, and validating crop models for the other forage crops studied based on the closest existing models. For maize forage, maize grain was utilized; for forage sorghum, grain sorghum; for pearl millet (*Pennisetum glaucum*), grain millet; and for winter forage small grains, wheat (*Triticum aestivum*). These models were utilized after altering their cultivar coefficients. Calibration and validation against local, actual and current studies were performed before running the models.

Forage systems were arranged in three growing seasons: spring-summer, summer-fall, and winter as it happens in north Florida dairy farm systems. All potential forage combinations were run for four N effluent ranges, the ten types of soils found in the study area, and the 43 years of daily weather data (1956-1998). Residual organic matter from one crop to the next was accounted for as well as other management choices that are common in these systems such as extra irrigation and harvests events.

2.4 Calibration and Validation of DSSAT Crop Models

Since the main objective was to assess potential N leaching, biomass accumulation (that determines N uptake) was used as the variable in the calibration and validation processes. Cultivar coefficients were manipulated to match field data of biomass production without distinguishing between grain and forage (G. Hoogenboom and K. Boote, personal communication). The most important data sources used for calibration and validation are listed in Table 2.

The calibration and validation was similar for sorghum, corn, millet, and winter forges. For brevity, only the calibration and validation for forage sorghum is described. Woodard et al. (2002) found that forage sorghum between early August and early November will produce between 7.3 and 11.1 Mg ha^{-1} of dry matter and uptakes between 99 and 150 kg N ha^{-1}, under large N applications of manure effluents.

Environmental conditions of the actual field experiment were recreated with the DSSAT v4.0. Soil data of the series Kershaw for Gilchrist County were obtained from the Soil Survey Geographic Database (SSURGO) (Weatherspoon et al., 1992).

-Place Table 2-

Daily weather data from Levy (29.42 N, 82.82 W) compiled by Mavromatis et al. (2002) were used. Manure effluent was set up to be applied in two applications every month containing 21, 29, or 38 kg N ha^{-1} each, for a total of 500, 690, and 910 kg N ha^{-1} in a year as detailed in the study. The sorghum crop received 6 applications with a total of 132, 174, and 228 kg N ha^{-1}, respectively. In addition to the water in the liquid manure, extra irrigations were realized, so the crop would have only minimal stresses. A new cultivar called forage sorghum was created after the process of validation between the simulated and the experimental data.

Table 3 shows the final cultivar coefficients and Figure 3 presents a comparison between simulated and observed data (Woodard et al., 2002) for sorghum, corn, winter forage, and millet. As per graphs and RMSE in Figure 3, we concluded that crop models were appropriately simulating crop biomass, N uptake, and consequently N leaching.

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2.5 Manure N Application

Dairy farm fields received a highly variable amount of manure N depending on herd size, land available, and waste management system. Monthly rates of manure N received by fields were estimated for all variety of north Florida dairy farms. These were estimated by simulating dynamic cow flows in Markov-chains integrating real data from seasonality, culling rates, reproduction rates, and milk production of north Florida dairies (for details see Cabrera, 2004). These rates varied between 20 and 160 kg ha^{-1} month^{-1}. Considering that sprayfields usually have two applications per month, four treatments were arranged at 10, 20, 40, and 80 kg ha^{-1} application^{-1} in the DSSAT v4.0 models.

2.6 Analyses

Daily cumulative N leached (kg ha^{-1}) and biomass (kg ha^{-1}) outputs from the simulations were compiled monthly for the span of the study period (1956-1998). All months were classified according to ENSO phases and results were summarized by the factors incorporated in the simulations: 12 months x 3 ENSO phases x 4 Manure N applications x 10 soil types x 11 forage combinations.

3 Results

3.1 Forage Crop Systems in North Florida Dairies

Interviews and focus groups indicated that there are three marked seasons in the north Florida forage calendar: spring-summer (from late March or early April to mid July), summer-fall (from late July or early August to early or mid November), and fall-winter (from late November or early December to mid March) (Table 4).

Spring-summer crops

Three crops were reported during this season in dairy farm fields: maize, bermudagrass, and bahiagrass. Sorghum or pearl millet could also be an option in this season, but were not reported. Maize is planted for silage and always as a part of a sequence of crops. Bermudagrass and bahiagrass are used for hay, haylage (silage in the field), or grazing, and they are also usually part of a sequence of crops. It is possible to plant maize over the bermudagrass or bahiagrass in this season (sod-planting). One to three cuttings are expected for the grasses during this season (two are usual), if they are not grazed.

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Summer-fall crops

During the summer-fall season, sorghum and millet are common, although continuation of grasses from the previous season is also common. Some farmers grow maize for silage in this season or let the bermudagrass or bahiagrass re-grow, if they were sod-planted in spring-summer. Another option, mentioned by one farmer, was the re-growth of perennial peanut. Sorghum, millet, perennial peanut, and the grasses can be used for hay, haylage, or grazing. One to three cuttings are expected for the grasses and one to two cuttings for sorghum and millet, if they are not grazed.

Fall-winter crops

Winter forages are usually small grains or ryegrass. Small grains often used are rye, oats (*Avena sativa*) or wheat. Bermudagrass and bahiagrass are perennial, but are dormant during this season and can be multi-cropped with other species usually, non-till sod planted. Small grains are used for hay or haylage; ryegrass is preferred for silage. Winter small grains could be cut one to four times (two cuts are usual), if they are not grazed. Clover (*Trifolium* spp.) was also mentioned as an option by one farmer, intercropped with several other grasses.

Sequences of forages

If bermudagrass or bahiagrass is established and allowed to re-grow in the spring-summer season, it will continue growing in the summer-fall season, and no other crops will be grown on the same field until the fall-winter season. However, if maize is grown in spring-summer planted into one of those grasses, the grass will be allowed to re-grow in the summer-fall season.

If maize, sorghum, or millet is planted in the spring-summer season, any summer-fall crop will be possible. In the fall-winter season, any small grain or ryegrass could follow any summer-fall crop. If perennial grasses are not established, the most common sequence of forages is silage maize in spring-summer followed by sorghum or millet in the summer-fall, and any small grain or ryegrass in the fall-winter. If grasses are established, a common sequence is grass-grass-small grain or ryegrass. Bermudagrass is much more common than bahiagrass and both are much more common than perennial peanut.

Rye, oats, and wheat are very similar forages and farmers use them indistinctly. Ryegrass was indicated as having better-quality forage, but requires more care and time. It is very common to mix all these winter forages in the fields.

Farmers try to have a crop in the field at all times, with brief windows between the growing seasons. The regulatory agencies strongly recommend this practice in order to ameliorate the risk of N leaching.

3.2 Nitrogen Leaching

At least some amount of N leaching is predicted to occur in every month of the year; however, there was great variability in those amounts depending upon climate conditions, season of the year, soil characteristics, crops in the fields, and amounts of manure N applied. There was consistently a much greater likelihood of higher N leaching during El Niño years than during neutral years and in neutral years than in La Niña years (Figure 4). Relative variations in N leaching among ENSO phases due to changes in other biophysical and environmental factors (i.e., crops and soils) were not monotonically distributed; but always hold that higher amounts of N leaching occurred in El Niño and lower amounts in La Niña phases.

Absolute amounts of N leaching (kg ha^{-1} yr^{-1}) when the manure N application was 40 kg ha^{-1} mo^{-1} varied from more than 500 (El Niño phase, soil type 6: Millhopper-Bonneau, and corn-sorghum rotation) to less than 260 (La Niña phase, soils type 2: Arredondo-Jonesville-Lake and bermudagrass or bahiagrass rotation) (Figure 4). Absolute differences between El Niño and La Niña phases varied from (kg ha yr^{-1}) less than 17 (soil type 5: Penney-Kershaw and bermudagrass rotation) to more than 64 (soil Otella-Jonesville-Seaboard and corn-sorghum rotation). There was no consistence in the differences between neutral phases and El Niño or La Niña phases regarding N leaching, but usually neutral N leaching amounts were closer to El Niño phases; for example N leaching (kg ha yr^{-1}), in soil type 5, for millet-corn rotation in neutral phase was almost the same as for El Niño phase, however for corn-sorghum rotation N leaching in neutral phase was much closer to La Niña phase than to El Niño phase.

Monthly N leaching predictions (kg ha^{-1} mo^{-1}) indicated great variation among ENSO phase distributions throughout the year and identified a critical period (Dec-Jan-Feb) when the N leaching is substantially superior to the rest of the year and a critical single month (January) when the N leaching could represent as much or more than half of the total year (Figure 5).

Figure 5 shows a typical N cycle in dairy fields in north Florida depending upon crop patterns and climate conditions. During January, the distribution of N leaching predicted was slightly skewed to the right (high measurements) and overall presented more N leaching in El Niño than neutral and La Niña years. It is also predicted for El Niño phase higher N leaching in the months of December, August, September, and November; for La Niña years, February; and for neutral years, March, April, and May. For the months of June, July, and October the distributions of the three phases are very close and the actual N leaching amounts will depend of the specific climatic conditions. Notice that usually during neutral years, there was higher variability of monthly N leaching than during the other ENSO phases.

Differences in the predicted amounts of N leached (kg ha^{-1} mo^{-1}) when changing the applications of manure N effluent varied differently. In the case study of the month of October (Figure 6), this was almost imperceptibly when the applications doubled from 10N to 20N, however this increased substantially when the applications went to 40N and increased exponentially when applications went to 80N (Figure 6). Consistent with previous results shown in Figure 5, distributions of the three phases are very close in the month of October. It was noticed that the variability of the results also increased with higher amounts of manure N applied, demonstrated in substantially larger ranges of outputs in the distributions.

A case study of relative amounts of N leaching by different crop systems in soils type 3: Bonneau-Blanton-Eunola can be studied by comparing Figures 7 and 8. As previously, in January, winter forages showed substantially higher amounts of N leaching (between 70 and 180 kg ha^{-1} mo^{-1}) (refer to Figure 7, soil type 3) than spring or summer crops (Figure 8) that ranged between 2 to 95 kg ha^{-1} mo^{-1}.

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In spring and summer, millet and sorghum presented greater amounts of N leaching, while bahiagrass and bermudagrass presented much lower amounts (Figure 8); corn presented medium amounts, in the higher end during spring and in the lower end during summer. There were higher predicted amounts of N leaching for El Niño phases and lower amounts for La Niña phases, for all crops in spring and summer, although this was less marked for bermudagrass and bahiagrass during fall.

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During January, the crop models estimated more N leaching for El Niño phases and lower for La Niña phases in all 10 soils found in the study area (Figure 7). Soils type 3, 4, 5, 6, and 9 presented overall higher N leaching amounts, while soils type 1, 2, 7, 8, and 10 presented overall lower N leaching, however lower variability was noticed for soils type 3 and 5.

4 Discussion

Findings from this study of both N leaching and biomass accumulation are consistent with data reported by the literature. Absolute values and trends of N leaching and its intra and inter annual variability are highly consistent with previous field experiments. For example, by comparing results presented in Figures 4 to 8 with field studies in the same location as Woodard et al. (2002, 2003) and Macoon et al. (2002), it was noticed, high level of agreement between the simulations and the experiments regarding: a) absolute values of dry matter accumulation of individual and yearly crops rotations, b) seasonality of substantially higher amounts of N in the soil solution during winter, c) higher N removal and consequently less N leaching with grasses (bermudagrass and bahiagrass), and d) sudden increment in N leaching after a threshold of manure N application above 500 kg yr^{-1}. Previous field studies did not last more than a few years and based on them it is not possible to infer differences among ENSO phases; fortunately this study, its documentation, and its corroboration with previous literature allowed us to estimate the risks of N leaching by ENSO phase and their distributions.

By studying the outcomes of the simulations it is possible to infer management strategies that evidence the trade-off between N leaching and biomass production. In Figure 4 we set up arbitrarily levels of N leaching and biomass at 300 and 3000 kg ha^{-1} yr^{-1}, respectively, which divide each graph in four panels, which could be assumed as follow: low N leaching, low biomass; low N leaching, high biomass; high N leaching, low N leaching; high N leaching, high biomass. From these, farmers' objective would be high biomass accumulation and, if possible, low N leaching; while environmental agencies would pursue mostly low N leaching levels. For example, there would be high biomass accumulation with corn-sorghum rotations for most of the soils (except soil type 3), but there would be high biomass together with low N leaching only with soils type 2, in neutral and La Niña years with soils type 8 and 1, and in neutral years with soils type 5 (Figure 4B). However, because soil type is a fixed characteristic that farmers can not change,

Figure 4A would give interesting guidelines of this trade-off by a specific soil type (in Figure 4A, soil type 5) and the potential crop options. Evidently, crop rotations for all ENSO phases consisting of corn-bermudagrass, and corn-corn, and during La Niña years of millet-corn and corn-sorghum would be highly advisable since the point of view of the farmer looking for high production returns and low N leaching. Following the same logic, if the regulation pressure is too high requiring farmers to decrease N leaching drastically, crop rotations consisting of bahiagrass, bermudagrass, or a rotation of corn-bahiagrass would be advisable for the least amounts of N leaching.

Following on the previous discussion, knowing that the interviews and focus groups in this study indicated that major changes for dairy farms' environmental accountability regarding N leaching would be based mostly in adjusting crop rotations, it is evident that seasonal climate forecast plays a critical role in crops selection since they are highly sensitive to daily weather represented in seasonal climate variations. Great amounts of N lost could be prevented by selecting the right crops for a set of given conditions including seasonal climate predictions. This analysis should be performed in an individual farm-by-farm basis.

Figure 5 describes a common N cycle in north Florida dairy farm fields under constant high pressure of manure effluent applications. A build-up of N in the soil starts early in spring (April) when a new agricultural year begins. During April, dominant low precipitation conditions (Figure 2), a new crop in high requirement of N, and a depletion of N during previous winter create conditions to decrease N leaching; in summer, rapid plant growth sucks great amounts of N and decrease amounts of N leaching; in fall, high N uptake would remain moving towards the end of the season with N build up in the soil; and in winter, low crop growth and low N uptake increases the amounts of N leaching. This intra-annual soil N cycle impacted by seasonal climate variability, is also be impacted by inter-annual climate variability represented by ENSO phases. In this study, it was not considered sequential carryover of N from year to year assuming that the dynamics of the soil have reached steady state, however it would be interesting to study the N cycle in the soil (and perhaps its movement to ground and superficial waters) for a series of years.

Even though beyond the scope of this study, we can conjecture here that it would be desirable to couple results from crop simulation models with whole dairy mechanic and economic models to assert holistic management strategies toward economic and ecologic sustainability of these systems.

The higher (lower) N leaching (biomass accumulation) predicted for El Niño years than Neutral years or La Niña years is attributed to climate patterns, mostly the number and intensity of rainfall events and temperature cycles. Nitrogen in the soil will be lixiviated easily with strong rainfalls, while it could be promoted in its absorption by the plants if there are frequent soft rainfalls, even though the overall rainfall amounts in both cases are similar over a period of time. Temperature and its variations will impact the N leaching either because it promotes different plant growth and consequently different N uptake or because it impacts the speed of the decomposition in the soil. An attempt to relate the N leaching with the Japan Meteorological Index (JMA) (O'Brien et al., 1999), used to predict the El Niño Southern Oscillation phases, showed little or no correlation.

There is great variability in the interaction of soil types and months of the year regarding N leaching and biomass accumulation. Water holding capacity, pH and permeability of soils are believed to hold most of the causes for these differences. Soils with very low permeability and higher pH will facilitate the leaching of N, which also will vary throughout the year, and at the same time it will determine higher biomass accumulation. There is more biomass accumulation for soils with higher N leaching rates because in these intense systems there will be little stress because of the lack of N, other nutrients, and/or water as these fields have irrigation systems that deliver the manure effluent and artificial irrigation as needed.

5 Conclusions

The use of crop simulations was critical in recognizing trends, interactions, and identifying absolute values of N leaching and biomass accumulation under different conditions of climate, manure N application, soil type, and forage systems. It would be impossible to design and conduct a field experiment of this magnitude.

It is consistent that higher amounts of N leaching are expected during El Niño years and lower amounts during La Niña years. Higher variability in N leaching is expected in neutral years. During winter, specifically between December and March more than 50% of a year N leaching occurs.

In general, the best forage systems to prevent N leaching are those that start in spring-summer with bermudagrass or maize; have bermudagrass, bahiagrass or maize in summer; and finish with winter forages. The systems that leach the most are those that include millet and/or sorghum. Bahiagrass could also leach high N in conditions of high manure N application.

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Figure 1. Study area, dairy farms, and soil types

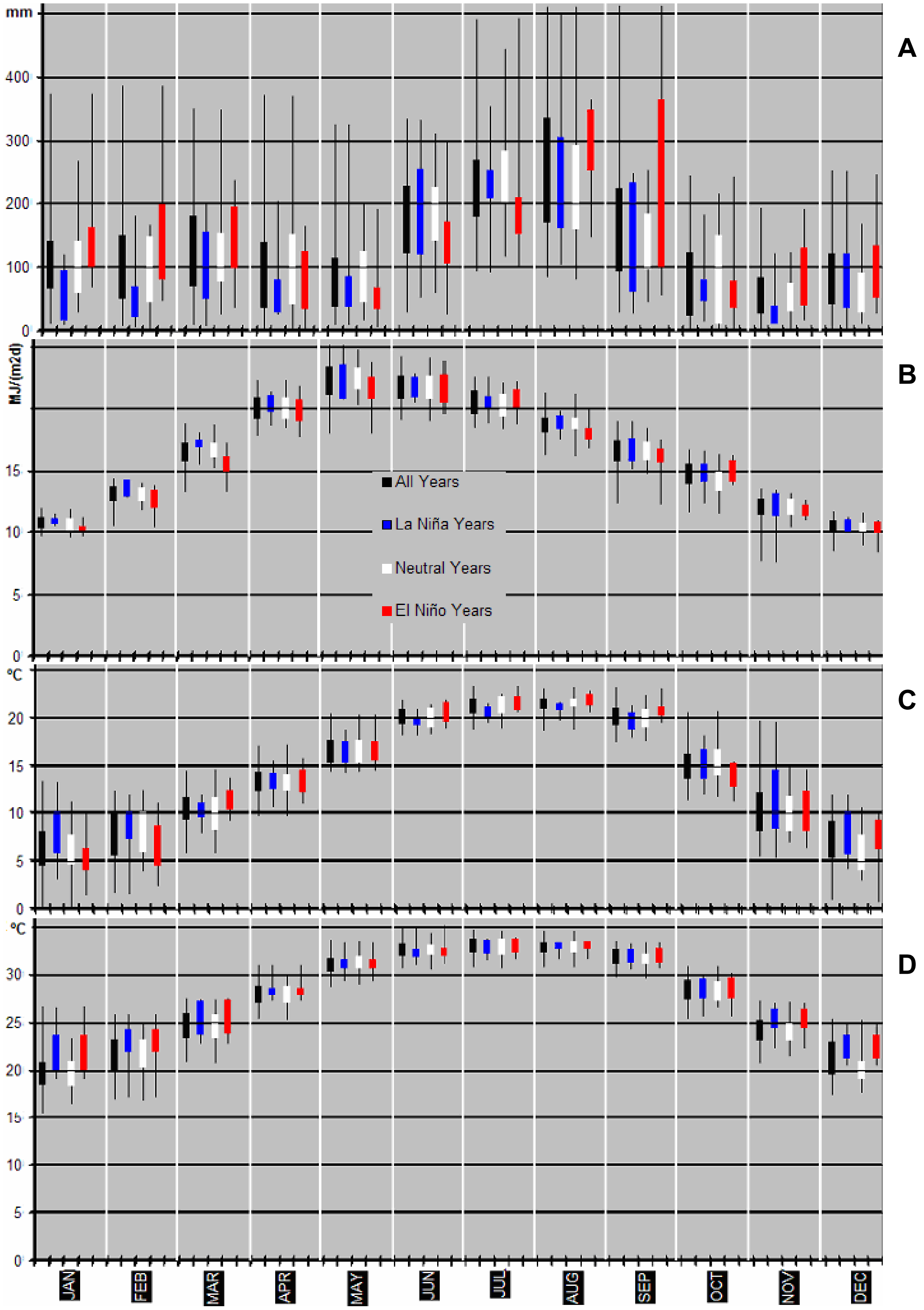

Figure 2. Climate for different ENSO phases (1956-1998) in north Florida. A) Precipitation. B) Solar Radiation. C) Minimum Temperature. D) Maximum Temperature. Station: Levy (29.42 N, 82.82 W). Source: Mavromatis et al. (2002).

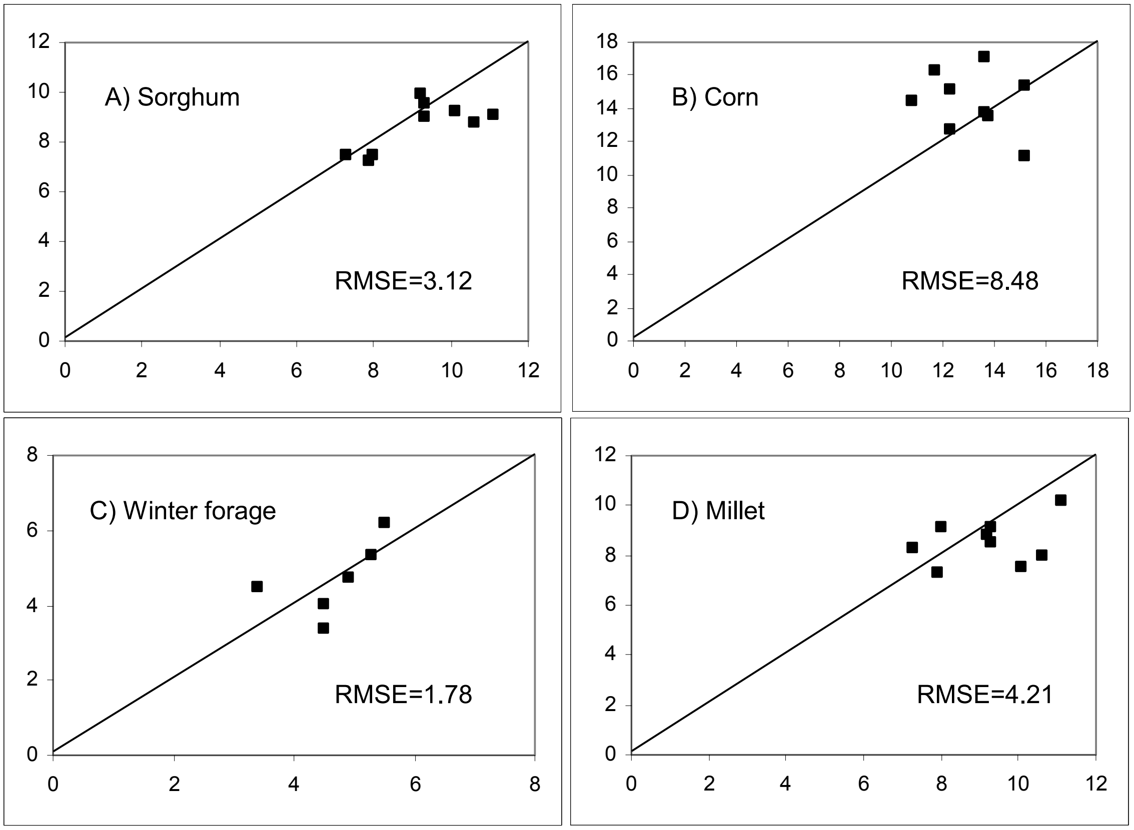

Figure 3. Forage sorghum: Observed and simulated biomass production, Bell, 1996-1998 and overall Root Mean Square Errors (RMSE).

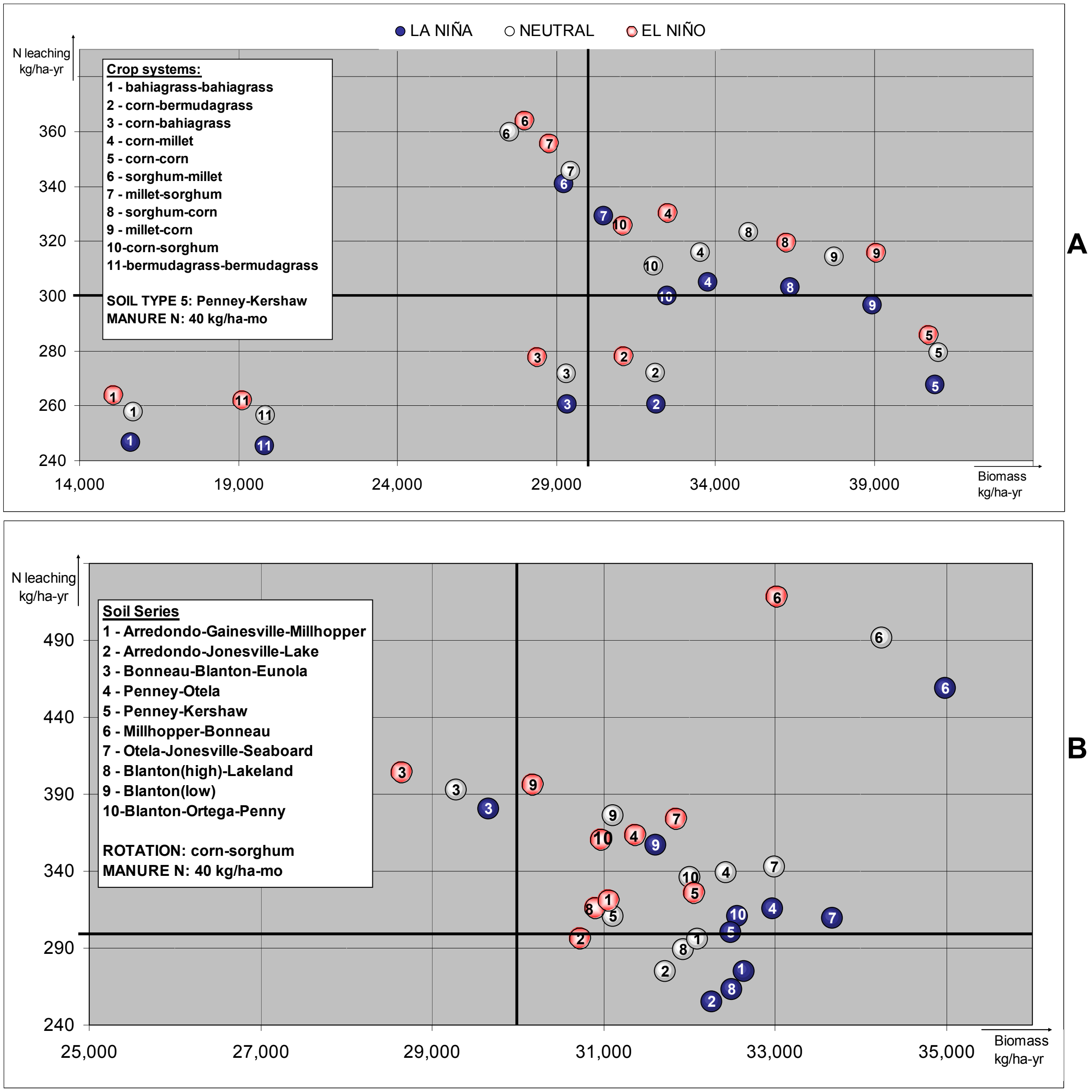

Figure 4. Trade off of N leaching and biomass accumulation for different ENSO phases (La Niña, Neutral, El Niño) when applied 40 kg ha^{-1} mo^{-1} for A) different crop rotations with soil type 5: Penney-Kershaw and B) for different soil types with corn-sorghum rotation.

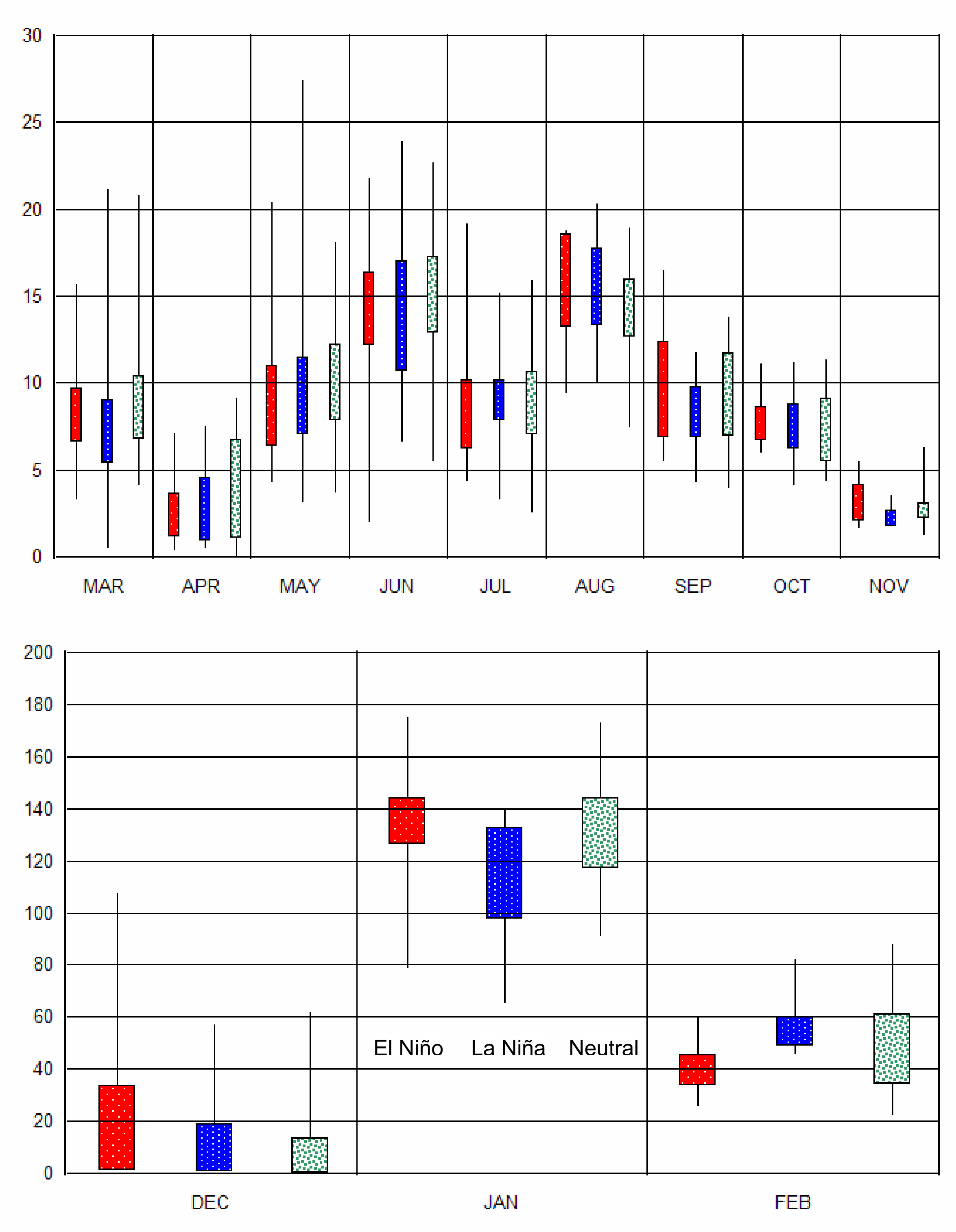

Figure 5. Monthly N leaching (kg ha^{-1}) distribution by ENSO phases for a rotation consisting of corn-bahiagrass in soil type 5: Penney-Kershaw when applied 40 kg ha^{-1} mo^{-1} of manure N effluent. Maximum, 75-percentile, 25-percentile, and minimum values in each distribution.

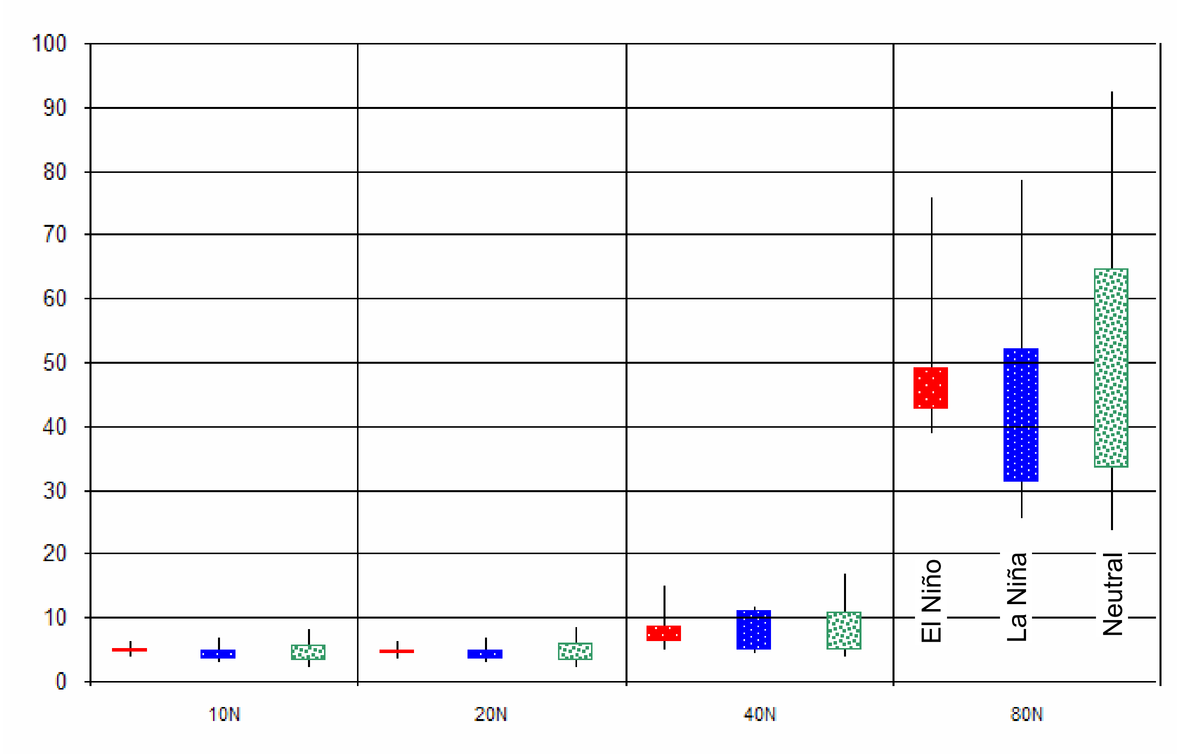

Figure 6. Predicted N leaching in the month of October (kg ha mo-1) under different amounts of manure N applied for soil type 7: Otela-Jonesville-Seaboard and bahiagrass rotation. Maximum, 75-percentile, 25-percentile, and minimum values in each distribution. Note: the horizontal axis represents the amount of manure N as effluent applied twice a month (i.e., 20N means 20 kg N applied twice = 40 kg).

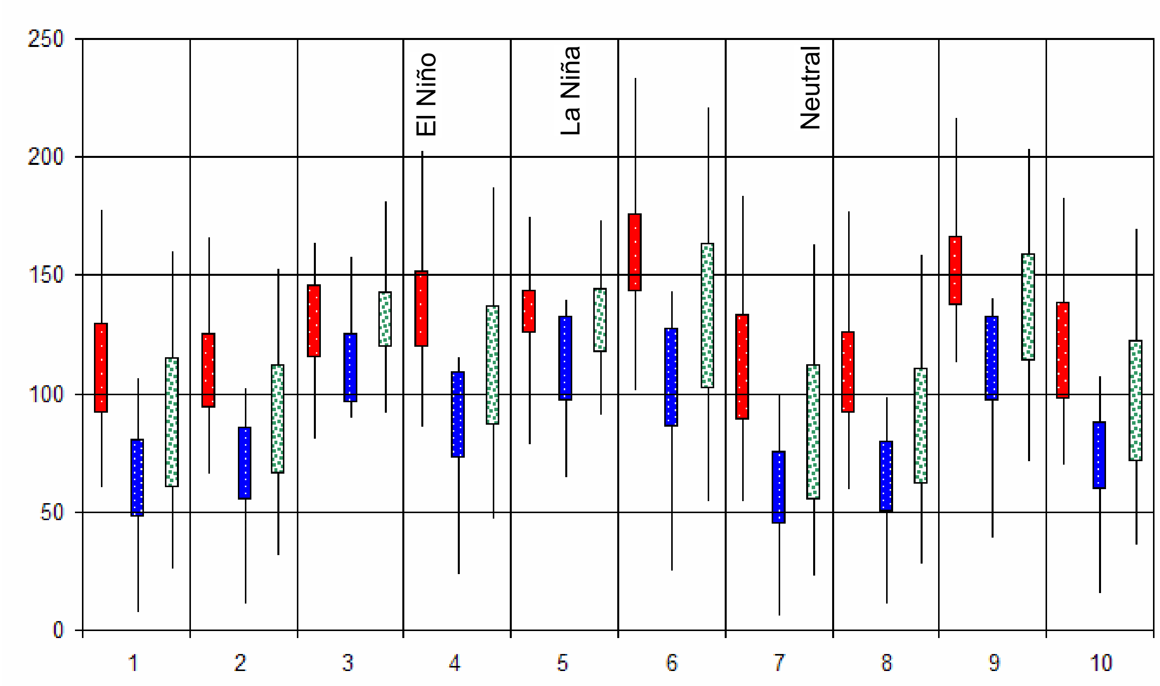

Figure 7. Nitrogen leaching in January for winter forage when applied 80 kg manure N mo^{-1} for all soil types found in north Florida represented by their codes: 1=Arredondo-Gainesville-Millhopper, 2=Arredondo Jonesville Lake, 3=Bonneau Blanton Eunola, 4=Penney Otela, 5=Penney Kershaw, 6=Millhopper Bonneau, 7=Otela Jonesville Seaboard, 8=Blanton(high) Lakeland, 9=Blanton(low), 10=Blanton Ortega Penny. Maximum, 75-percentile, 25-percentile, and minimum values in each distribution.

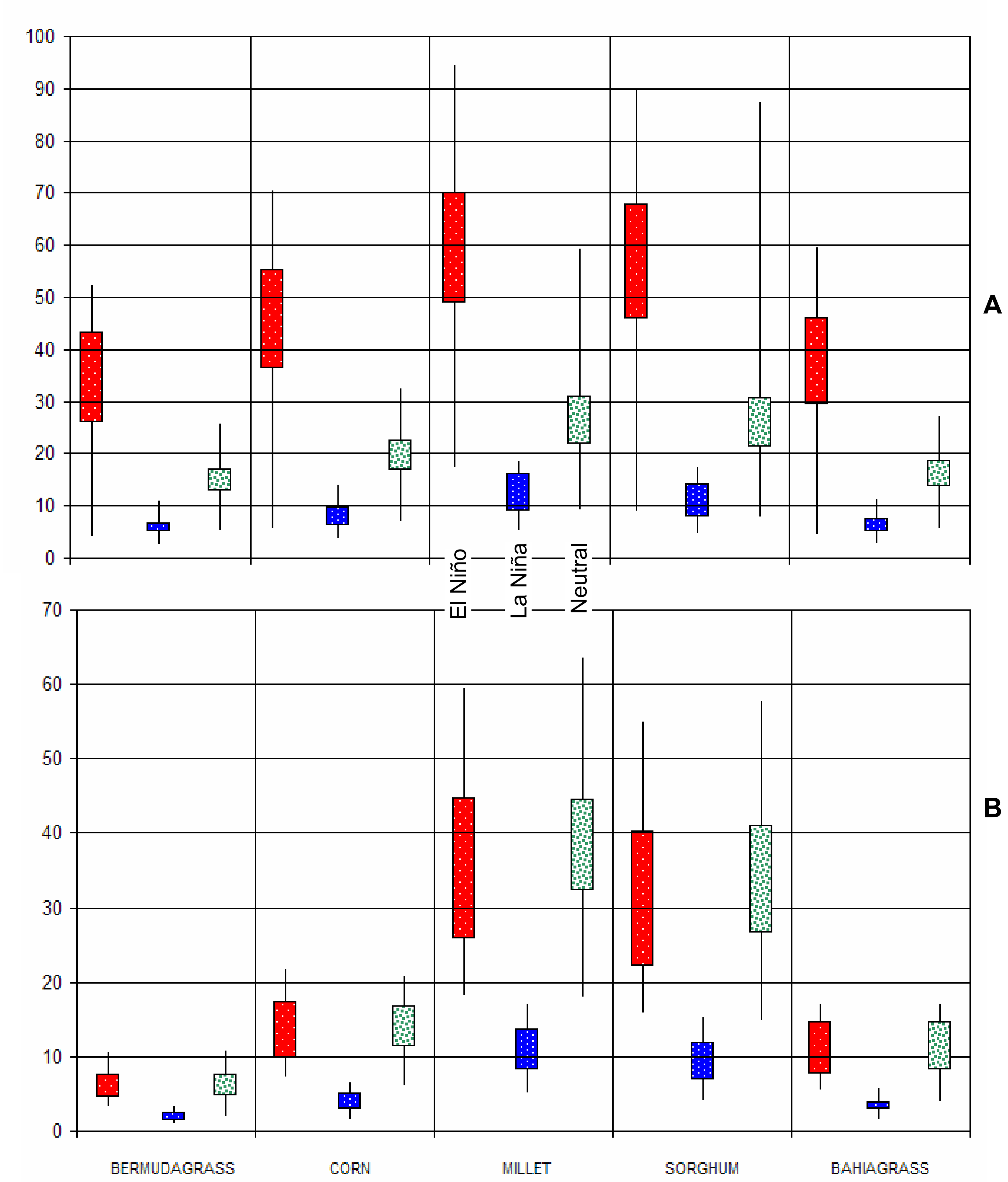

Figure 8. Monthly N leaching (kg ha^{-1}) distribution by ENSO phases when applied 40 kg ha^{-1} mo^{-1} of manure N effluent in soil type 3: Bonneau Blanton Eunola for the months of A) June and B) September. Maximum, 75-percentile, 25-percentile, and minimum values in each distribution.

Table 1. Soil types, some characteristics, and their sources of information used for the study

Type	Series	County	Drainage[1] Rate	CEC[2] meq 100 g^{-1}	pH[3]	Survey
1	Arredondo-Gainesville-Millhopper	Alachua	0.75	6.0	5.9	Thomas et al., 1985
2	Arredondo-Jonesville-Lake	Alachua	0.65	5.0	6.3	Thomas et al., 1985
3	Bonneau-Blanton-Eunola	Gilchrist	0.80	6.6	5.6	Weatherspoon et al., 1992
4	Penney-Otela	Gilchrist, Lafayette	0.80	3.6	4.9	Weatherspoon et al., 1992
5	Penney-Kershaw	Gilchrist	0.75	3.2	4.7	Weatherspoon et al., 1992
6	Millhopper-Bonneau	Levy	0.85	7.0	5.0	Slabaugh et al., 1996
7	Otela-Jonesville-Seaboard	Levy	0.75	5.5	5.3	Slabaugh et al., 1996
8	Blanton(high)-Lakeland	Suwannee	0.60	2.7	5.1	Houston, 1965
9	Blanton(low)	Suwannee	0.80	7.4	5.3	Houston, 1965
10	Blanton-Ortega-Penny	Lafayette	0.75	5.1	5.3	Weatherspoon et al., 1998

Note: Drainage, CEC, and pH are only for the first soil layer. [1]0.60 (well), 0.75 (somewhat excessive), 0.85 (excessive). [2]Cation Exchange Capacity < 3.0 (extremely low), 3.1-5.0 (very low), 5.1-7.0 (low), 7.1-10.0 (medium). [3] < 5.0 (very strongly acid), 5.1-5.5 (strongly acid), 5.6-6.0 (moderately acid), 6.1-6.5 (slightly acid).

Table 2. Information sources for calibration and validation of forage crops in north Florida dairy farm systems

Study/Source	Location	Weather	Soil Series	Observations
Woodard et al. (2002)	North Florida Holsteins Farm, Inc. Bell. 29.73 N, 82.85 W	1996-1998	Kershaw	Several forages: maize, sorghum, rye. Manure effluent applied in rates of 500, 690, and 910 kg N ha^{-1} year^{-1}
Fontaneli et al. (2000) (2001)	Forage Field Evaluation Laboratory. Gainesville. 29.08 N, 82.42 W	1996-1997	Sparr	Cool season forages: comparing winter multi-crops. Warm season forages: comparing three varieties of millet and two varieties of sorghum
Wright et al. (1993)	North Florida Research and Education Center. Quincy. 30.40 N, 84.27 W	1992	Norfolk	Millet and sorghum. Different treatments and purposes
Johnson et al.	Tifton, GA. 31.43 N, 83.89 W	Before 1991	Tifton	Maize and rye with different rates of Manure effluent applied
Survey north Florida dairy farms	Suwannee River Basin	Several years	Several types	Not always precise information, but real and trustworthy

Table 3. Coefficient values and coefficient definitions of modified crops in DSSAT

Forage	P1	P1V	P1D	P2	P20	P2R	P5	G1	G2	G3	PHINT
sorghum	500.0				10.5	90.0	540.0	5.0	6.0		44.0
Millet*	600.0				10.0	90.0	540.0	5.0	6.0		44.0
Maize	200.0			0.52			940.0		620.0	8.5	38.9
winter forage		47.0	64.0				360.0	28.0	25.0	1.3	80.0

P1: Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature (10 °C sorghum, 8 °C millet and maize) during which the plant is not responsive to changes in photoperiod.

P1V: Relative amount that development is slowed for each day of unfulfilled vernalization, assuming that 50 days of vernalization is sufficient for all cultivars

P1D: Relative amount that development is slowed when plants are grown in a photoperiod 1 hour shorter than the optimum (which is considered to be 20 hours).

P2: Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours).

P20: Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate. At values higher than P20, the rate of development is reduced.

P2R: Extent to which basic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P20.

P5: Thermal time (degree days above a base temperature (10 oC sorghum, 8 oC millet and maize, 1 oC winter forages) from beginning of grain filling (3 4 days after flowering) to physiological maturity.

G1: Scaler for relative leaf size (sorghum and millet); Kernel number per unit weight of stem (less leaf blades and sheaths) plus spike at anthesis (winter forages)

G2: Scaler for partitioning of assimilates to the panicle (sorghum, millet, maize); Kernel filling rate under optimum conditions (winter forages)

G3: Kernel filling rate during the linear grain filling stage and under optimum conditions (maize); Non stressed dry weight of a single stem (excluding leaf blades and sheaths) and spike when elongation ceases (winter forages)

PHINT: Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances

* Conversion of solar radiation was additionally set to 0.42, which originally was 0.50.

Table 4. Forage systems and their seasonality in north Florida dairy farms

SPRING - SUMMER	SUMMER - FALL	FALL - WINTER
BAHIAGRASS	BAHIAGRASS	RYE, OATS, WHEAT, OR RYEGRASS
BERMUDAGRASS	BERMUDAGRASS	RYE, OATS, WHEAT, OR RYEGRASS
CORN	SORGHUM	RYE, OATS, WHEAT, OR RYEGRASS
CORN	BERMUDAGRASS	RYE, OATS, WHEAT, OR RYEGRASS
CORN	BAHIAGRASS	RYE, OATS, WHEAT, OR RYEGRASS
CORN	MILLET	RYE, OATS, WHEAT, OR RYEGRASS
CORN	CORN	RYE, OATS, WHEAT, OR RYEGRASS
MILLET*	SORGHUM	RYE, OATS, WHEAT, OR RYEGRASS
MILLET	SORGHUM	RYE, OATS, WHEAT, OR RYEGRASS
SORGHUM*	MILLET	RYE, OATS, WHEAT, OR RYEGRASS
SORGHUM	CORN	RYE, OATS, WHEAT, OR RYEGRASS
	PERENNIAL PEANUT* **	CLOVER**

MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR

* Not found in the interviews, but they are possible. ** Not common and not simulated with DSSAT.