

A

Memorandum

To: FDEP

From: CDM

Date: February 16, 2007

*Subject: Review and Summary of Agricultural BMP Work in the Middle
Suwannee River Basin
Technical Memorandum*

I. Summary

This Technical Memorandum (TM) presents the results of a literature search and review of Suwannee River Basin (SRB) agricultural BMP research and demonstration projects that were conducted from the year 1990 through 2005. This list has been compiled to assist FDEP and other stakeholders with identification and implementation of BMPs to control and reduce nutrients (nitrogen and phosphorous) in the Middle Suwannee River Basin and other related areas.

This TM and bibliography is the updated draft deliverable for Task 3 of Task Assignment 013.03/06-006.

The goal of the identified projects was the development, application, verification, and recommendation of methods, measures, or practices designed to mitigate surface and groundwater nutrient (nitrogen and phosphorous) pollution impacts from agricultural operations conducted within the SRB. This TM presents summary information for 84 of the 88 listed publications and CDM is attempting to add another 12 publications as available.

The literature search and review is documented in the annotated bibliography, which is included in Section II. The bibliography contains document citations, original abstracts (if applicable), and summaries of key findings. Review of the literature included in the annotated bibliography suggests that agricultural activities of particular concern within the SRB fall within the following general categories:

- Vegetable fertilization and irrigation management;
- Dairy and poultry operations management (e.g., animal and waste management);
- Application of dairy and poultry waste effluent on sprayfields; and

- Agricultural erosion and sedimentation management.

As noted in the various studies, reports, and papers, there are a number of agricultural methods that can be used at the farm and regional scale to reduce various forms of both nitrogen and phosphorus loadings to the receiving waters. Several authors have identified reduced nitrogen and phosphorus leaching and groundwater transport by variations in:

- Irrigation and drainage (type, timing, amount, and consideration of rainfall and evapotranspiration),
- Fertilization (timing, type, and amount),
- Crop management and rotation (seasonal variation, variable forage),
- Soil conservation and grading (terraces, alleys, and stream and wetland buffers),
- Manure management (collection, disposal offsite, and reuse), and
- Animal management (feed sources and amounts, variable forage, fencing, and stream and wetland buffers).

The literature also suggests that quantifying the level of effectiveness of any one BMP or combinations of BMPs in terms of nitrate or phosphate load reduction in surface and ground water is a complex undertaking, particularly due to variable site conditions and that statistically valid effects of BMP implementation can take a considerable amount of time to observe in the field. Consequently, a relatively small number of the research/demonstration projects that are included in the annotated bibliography report on the numerical effectiveness of BMPs in reducing nutrient losses to the environment; rather, for the most part, a qualitative scale is used (relative percent reduction).

In those cases where numerical reductions in nutrient loads were reported, the projects were evenly divided between actual field experiments, and computer simulations. Nutrient reductions generally ranged from 5 to 50%, with some reported reductions in the 50 to 80% range, depending on the parameter and scale of implementation. In addition, different methods to test for nutrient loading and transport were identified and evaluated for agricultural areas.

In addition to the publication listed here, the Florida TMDL Protocol Section 7 (Version 6, 2005) also contains summary information sheets and additional references for agricultural BMPs (www.dep.state.fl.us/water/tmdl/index.htm).

I.1 Vegetable Fertilization and Irrigation BMPs

Research and demonstration projects that fall within the general category of vegetable fertilization and irrigation have targeted the following types of BMPs:

- Fertilizer application rates;

- Timing of fertilizer application; and
- Irrigation types and scheduling.

Results of documented field monitoring and computer simulation projects suggest that the implementation of these types of BMPs can reduce the leaching of nitrate-N in groundwater from 35 to 50 percent. From a qualitative perspective, other projects indicate that BMPs that target these agricultural activities are effective in reducing nutrient losses to the environment and, therefore, their implementation is highly recommended.

I.2 Dairy and Poultry Operations BMPs

Computer simulations of dairy and poultry operations that incorporate multiple factors in the development of applicable BMPs, suggest that reductions in nitrate-N leaching can reach almost 80 percent for poultry operations, and can range from 25 percent to 55 percent for dairies. The USDA's National Resource and Conservation Service (NRCS) has demonstrated that at the farm scale, reductions of nitrate-N up to 75 percent can be achieved when implementing NRCS designed BMPs for poultry and dairy operations.

I.3 Animal Waste Application BMPs

A considerable amount of field research has been and continues to be conducted to evaluate the ability of forage crops in reducing dairy effluent nutrient leachate to groundwater. A variety of forage crops have been tested over 12-month cycles for periods of up to 5 years. The research suggests that of the tested variety of forages in cropping systems, Bermuda grass is superior in preventing nitrate-N from leaching out of the root zone, particularly during the initial cycles. However, Bermuda grass displayed a reduced ability to prevent leaching of nitrate-N over the latter cycles.

Research projects that target the mitigation of surface water nutrient pollution indicate that landscaped features (e.g., riparian stream and wetland buffers, vegetated filter strips and swales, etc.) can reduce the loss of nutrients to surface waters, particularly in those cases where manure is used for forage production in dairy operations. In one particular instance, the researcher documented a "fivefold reduction in nitrate concentration and a threefold reduction in phosphorous concentration in water moving from manured fields to streams or lakes".

I.4 Agricultural Erosion and Sedimentation BMPs

As discussed, research projects that target the mitigation of surface water nutrient pollution indicate that landscaped features (e.g., riparian stream and wetland buffers, vegetated filter strips and swales, etc.) can reduce the loss of nutrients to surface waters. In addition, nutrient reduction was identified for crop management and rotation (seasonal variation, variable

forage), soil conservation and grading (terraces, alleys, stream and wetland buffers), and retention-detention systems.

II. Annotated Bibliography

1. *Albert, M.A., Graham, W.D., and Graetz, D.A (2002). Monitoring and Modeling the Fate and Transport of Nitrate in the Vadose Zone Beneath a Suwannee River Basin Vegetable Farm. American Geophysical Union, Spring Meeting, #H32A-09.*

Original abstract: "The Suwannee River basin has received much attention in recent years due to increased nitrogen levels in the groundwater-fed rivers of the basin that could seriously affect the welfare of this ecosystem. Nitrogen levels have increased from 0.1 mg/l NO₃-N to more than 5 mg/L NO₃-N in many springs in the Suwannee Basin over the past 40 years. Nitrate concentrations in the Suwannee River itself have been increasing at the rate of 0.02 mg/L per year over the past 20 years. Suwannee River nitrate loads increase from 2,300 kg/day to 6,000 kg/day over a 33 mile stretch of the river between Dowling Park and Branford, Florida. Within this stretch of river, 89% of the nitrate loading appeared to come from the lower two-thirds, where agriculture is the dominant land use.

The objective of this research is to monitor and model the impacts of alternative nutrient and water management practices on soil water quality, groundwater quality and crop yield at a commercial vegetable farm in the Suwannee River Basin. Groundwater monitoring wells, suction lysimeters, soil cores and TDR probes are used to monitor water and nitrogen transport at the site. Periodic plant biomass sampling is conducted to determine nitrogen uptake by the plants and to estimate crop yield. Field data show that two-thirds of the nitrogen applied to the spring 2001 potato crop leached to groundwater due to excessive irrigation and poor nitrogen uptake efficiency by the potatoes. The DSSAT35-Potato Crop model and the LEACHM vadose-zone model were calibrated for the spring 2001 potato crop and used to predict nitrogen leaching and crop yield for alternative management practices. Simulation results show that by reducing the duration of irrigation, reducing the fertilizer application rate, and improving the timing of fertilizer applications, nitrogen leaching can be reduced by approximately 50% while maintaining acceptable crop yields. Results of this project will ultimately be used to develop best management practices (BMPs) and total maximum daily loads (TMDLs) for vegetable growing regions in the Suwannee River Basin."

Summary of Key Findings

Unable to obtain this report.

2. *Boote, K.J., and Jones, J.W. (2005). Integration and Verification of Water Quality and Crop Yield Models for BMP Planning. Presented at 65th Annual Meeting of the Soil and Crop Science Society of Florida and Florida Nematology Forum, Boca Raton, FL.*

Original abstract: "A new, long-term research project has been funded by the Florida Department of Agriculture and Consumer Services (FDACS) with the goal of improving water quality assessment and BMP implementation through the use of integrated modeling approaches and decision support tools in Florida. This 4-year project consolidates existing scientific program components in IFAS pertinent to modeling and water quality assessment, with efforts by a private engineering firm (Soil and Water Engineering Technology, SWET) that is implementing various water quality tools for use by FDACS throughout Florida. The work will integrate DSSAT crop yield models into the Watershed Assessment Model (WAM) developed by SWET to improve capabilities for assessing alternative BMPs relative to their projected effects on yield and water quality. Project scientists will test and improve models for important Florida crops for ability to predict growth, final yield, N uptake, and N leaching under different N fertilization and irrigation schedules. Other scientists will develop improved soil-water modules to better handle flatwood soil conditions and the plastic mulch bed systems typical for many vegetable crops in Florida. Another aspect will be the development and evaluation of in-season decision aids for use as a BMP for reducing N leaching. Finally, the project will develop recommendations for minimum data to be collected in BMP experiments or monitoring programs.

The group will document these models and their performance for users of the integrated system. The project involves faculty from a number of departments in IFAS. Our vision is to provide continuous updates and testing of various model components in the integrated system. The goal of FDACS is that the integrated tool will be used by FDACS and consultants to assist farmers in BMP planning relative to N and P fertilization and management aspects for important commodities in Florida. The WAM predicts watershed levels of N found in stream flow, for example, and will integrate large spatial regions of acreages cropped to particular production practices. The integrated WAM/DSSAT model system is seen by FDACS as a complement to intensive well monitoring methods to verify compliance to BMP plans."

Summary of Key Findings:

This is an on-going 4-year project and the report has not yet been developed (there are no results to report as of yet).

Per communication with Dr. Boote: "These two talks were never developed into a full paper, and all that exists is a PowerPoint presentation. This was primarily the presentation of the objectives of a research project that had relevance to many scientists at those two meetings, and a bit of research data from various places was added in."

This study and modeling has promise for use in nutrient controls in the watershed.

3. *Bottcher, A.B., and Rhue, D. (2000). Fertilizer Management – Key to a Sound Water Quality Program. Document CIR816. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville.*

Original abstract: "Fertilization, the process by which essential nutrients are artificially supplied to plants, is possibly the single most important practice used by growers to assure high yields. Each year Florida growers apply about 1.8 million tons of fertilizer at a cost of over \$250 million to grow over three billion dollars worth of crops. The net financial return from fertilization has been extremely high; however, recent evidence indicates we may be doing too much of a good thing, that is, over-fertilizing.

Over-fertilization leads to two serious concerns. The first is simply that of cost. Every dollar spent on fertilizer that does not return at least the same amount in increased yield is wasted. Besides wasting money, over-fertilization leads to a second, off-farm concern: pollution of groundwater supplies and downstream ecosystems due to transport of fertilizer nutrients. Discharges of nutrients into surface and subsurface waters can be detrimental to the beneficial uses, aesthetic appeal, flora and fauna of receiving water bodies. When this happens, growers suffer only indirectly; society as a whole bears the brunt of the cost. It would be impossible to tell Florida growers and water regulators what ought to be done on all farms to prevent fertilizer loss and subsequent water pollution because every farming situation is different. Instead, this publication is designed to impart a general understanding of the fertilization process so that predictions can be made for each particular situation. It will discuss the soil-plant environment and the process of plant uptake as these concepts relate to transport of nutrients in water. A basic understanding of these principles is the key to a fertilizer management program that conserves fertilizer and preserves water quality."

Summary of Key Findings

This Circular provides a good overview of nutrient management and in particular discussion of fertilizer application. The extension service publication reviews the nutrient cycle for N and P and the control and fate of N and P released by farming.

Bottcher and Rhue indicate that the nutrient cycle is controlled by soil type, temperature, tillage, moisture, vegetation type, and fertilizer (amount and form). Tillage, moisture, vegetation, and fertilizer can be controlled partially or completely by the agriculturalist. Nutrients can be released from farms via surface water or to the groundwater. Several forms of N are commonly released including nitrate, soluble organic matter and ammonium. However, only nitrate is commonly found in groundwater. Very little P, including orthophosphate or organic P, reaches the

groundwater in mineral soils, due to a high rate of adsorption to soil particles. If little iron or aluminum is present in the soils, significant movement of P in the groundwater may occur.

Important practices to reduce nutrient loss are soil conservation, efficient irrigation and fertilization techniques. Of these methods, fertilizer management is the most important factor in controlling nutrient losses. Uptake rates of nitrogen by plants range from 40% to 80% and range from 5% to 20% for phosphorus. Losses to leaching and runoff range from 5% to 30% for nitrogen and 0.5% to 5% for phosphorus. Therefore, the method of fertilizer management can significantly affect economic and environmental aspects of farming.

The method of applying fertilizer, form of the fertilizer, and rate of application can all significantly affect accessibility of nutrients to plants and the loss of nutrients. The paper incorporates several studies from the University of Florida to illustrate the importance of proper management. The paper compares a single application of soluble and slow-release N fertilizer and multiple applications of soluble nitrogen. When compared to the crops uptake requirement, it is clear that a single application requires the largest amount of fertilizer, which therefore has the greatest risk of nutrient loss. Multiple applications had the least amount of fertilizer applied. However, the effectiveness multiple applications depends on matching the fertilizer applications with the plant's optimal uptake characteristics. The effectiveness of slow-release fertilizers were found to be between single and multiple applications of soluble fertilizers. The effectiveness of these fertilizers is largely controlled by their ability to match changing rates of plant uptake. At the time of this paper, slow-release fertilizers were not achieving this match for most crops in an effective fashion.

In summary, the authors concluded "that fertilizer management that maintains yield while applying less fertilizer is the most effective way to reduce nutrient loss to the environment." To determine the most effective amount of fertilizer, the authors suggest a good program of soil testing be used, especially in sandy soils. Multiple fertilizer applications were found to require the least fertilizer. Challenges remain in using slow release fertilizer in an economic and environmental manner; however they have the potential to meet the needs of agriculture.

4. ***Cabrera, V.E. (2004). Modeling North Florida Dairy Farm Management Strategies to Alleviate Ecological Impacts Under Varying Climatic Conditions: An Interdisciplinary Approach. PhD Dissertation, University of Florida. Gainesville, FL.***

Original abstract: "High levels of nitrogen (N) in water affect human health and ecosystem welfare. Dairy waste is considered an important contributor to increased water N levels in the Suwannee River Basin. The main aim of the study was to assess management options that decrease N leaching in dairy systems under different

climatic conditions, while maintaining profitability. Whole dairy-farm system simulations were used to study economic and ecologic sustainability, which would be impractical to test with regular experiments. Dynamic, event-controlled, and empirical models were coupled with process-based and decision-making models to represent and test management strategies. User-friendliness and stakeholder interaction were always pursued. Eight focus groups and 24 dairy farmer interviews were conducted, and a collaborative user-friendly decision support system was created. The Dynamic North-Florida Dairy Farm Model (DNFDFM) uses Markov-chains to simulate probabilistic livestock reproduction, culling, milk production, and N excretion; process-based crop models to simulate forage production, N uptake, and N leaching; and linear programming optimization to tailor management strategies. The DNFDFM is an environmental accountability tool for dairy farmers and regulatory agencies capable of simulating any individual north-Florida dairy farm. Results indicated that north-Florida dairy farmers could maintain profitability and decrease N leaching 9 to 25% by decreasing crude protein in the diet, adjusting confined time of milking cows, and adjusting sequences of seasonal forages. During “El Niño” years, when higher rainfall and colder temperatures are experienced, 5% more N leaching is estimated compared with “Neutral” years; and 13% more compared with dryer and hotter “La Niña” years.”

Summary of Key Findings

The main objective of this PhD dissertation was to test management options that decrease nutrient overflow in dairy systems under different climatic conditions while maintaining profitability through the creation and use of simulation and optimization models. Whole dairy-farm system simulation was used to test alternative management strategies that would not be practical to test under regular experimental designs. Dynamic, event-controlled, process-based, and empirical models were coupled with optimization models to represent north-Florida dairy farms. The Dynamic North-Florida Dairy Farm Model (DNFDFM) was intended to be an environmental accountability tool for dairy farmers and regulatory agencies capable of simulating and optimizing any individual north-Florida dairy farm. Economic and ecological impacts were studied along with the effects of seasonal or climate variability for different dairy farm types.

Model results indicated that north-Florida dairy farms could substantially decrease N leaching and maintain profitability levels by adjusting crop sequences in spray fields, crop rotations in pastures, crude protein in the diet, and confined time of milking cows. Climatic conditions greatly affect N leaching: during “El Niño” years, when higher rainfall and colder temperatures are experienced, higher N leaching is estimated than in “La Niña” years, when lower rainfall and hotter temperatures are observed; in “Neutral” years, medium N leaching is registered. Farmers could vary crop proportions to better prepare for these different climatic forecasts.

The best forage systems to prevent N leaching are those that start in spring-summer with Bermuda grass or corn; have Bermuda grass, Bahia grass or corn in summer; and finish with winter forages. Systems that leach the most N are those that include millet and/or sorghum. Water holding capacity and pH among soil types may explain most of the great variability found in N leaching.

The applications of the DNFDFM in real farms, besides serving as a validation of the model, confirmed its usefulness in practical and real applications. For the 3 farms, in which it was validated, the optimizer was able to find better than current practices that would have lowered environmental impacts and still maintained profitability levels. By using the concept of “feasible” practices, which are those proposed by the optimizer that the farmer feels can be implemented, it was possible to reduce by 9%, 20%, and 25% the N leaching in a small, a medium, and a large farm in north-Florida. The optimization analyses found that some practices would be especially useful to north-Florida dairy farm operations in reducing N leaching. These are to decrease the crude protein in the diet and promote Bermuda grass instead of Bahia grass in pastures and spray fields.

5. *Cabrera, V.E., Breuer, N.E., Hildebrand, P.E., and Fraisse, C. (2005). Climate-based Management to Reduce Nitrate Leaching from Dairies in the Suwannee River Basin. IFAS Circular 1464. University of Florida, Institute of Food and Agricultural Sciences. Gainesville, FL.*

Original abstract: “Florida is the leading dairy state in the Southeast. It ranks 16th nationally in cash receipts for milk, 17th in milk production and 16th in number of cows (Florida Agricultural Statistics Service, 2004; <http://www.nass.usda.gov/fl/rtoc01.htm>). Milk and cattle sales from dairies contributed \$330 million directly into the Floridian economy in 2003. Dairy farmers in the Suwannee River Basin are aware that environmental issues will be among the greatest challenges they face in the near future. Dairy waste is thought to be an important factor contributing to nitrogen pollution in local waters. Dairy farmers are now required to comply with stricter environmental regulations, either under permit or under voluntary incentive-based programs. Dairies face increased regulation because of social pressure, while larger herds attract the attention of neighbors and activists concerned with odors, flies, and especially, potential leaching of nutrients that might influence water quality (Giesy et al., 2003). The Suwannee River Partnership (<http://www.srwmd.state.fl.us/features/suwannee+river+partnership/default1.htm>) states that over the last 15 years, nitrate levels in the middle Suwannee River Basin have been on the increase, and these elevated nitrate levels can cause health problems in humans as well as negative impacts on water quality. Evidence indicates that farms may reduce their total nitrogen loads by changing some of their management practices. Improvements in long-term seasonal climate predictions (6 to 12 months) such as those based on El Niño and La Niña forecasts, can play an important role in

implementing management strategies that dairy farmers in north Florida may adopt in order to pursue economic and ecological sustainability.

Summary of Key Findings

El Nino and La Nina seasonal forecasts can be used to implement management strategies to reduce the economic and environmental impacts on dairies in north Florida. The research documented in this Circular investigates the possible affects on forage crop growth and nitrate leaching based on the El Nino Southern Oscillation (ENSO). Multiple monthly simulations using Decision Support Systems for Agricultural Transfer (DSSAT) version 4.0 software, which were based on ENSO phase, manure nitrogen application rate, soil type, and forage system were made and analyzed.

The range of forage systems (the fodder plants, management practices, and sequences) used in North Florida dairies were identified for 21 dairies in the Suwannee River basin in cooperation with the Suwannee River partnership and the University of Florida Institute for Food and Agricultural Sciences. These forage systems were created, calibrated, and validated in the DSSAT model. Forage systems were divided into three growing seasons: spring-summer (late March or early April to mid July), summer-fall (late July or early August to early or mid November), and winter (late November to mid March). Crops included Bahia grass, Bermuda grass, corn, forage sorghum, pearl millet, and winter small grains.

The study used 45 year of meteorological data (1956 through 1998) to provide a long-term record of potential climatic conditions. This time period included 11 El Nino years, 10 La Nina years, and 23 neutral years, where a year was defined as October 1st through September 30th of the next calendar year.

The forage systems, meteorological data, 10 local soil types, and four treatments of manure (10, 20, 40, 80 kg/ha. application) were used as input in DSSAT software. DSSAT was used to simulate the monthly crop growth and yield and the soil nitrogen balances, which determines the amount of nitrogen lost to leaching. Results of these simulations indicated significant variation in nitrate leaching based on the ENSO phase, forage system, and soil type.

Nitrate leaching in El Nino years were greater than in neutral or La Nina years. January and February were found to be critical for nitrogen leaching, with the months predicted to contribute more than 50% of the annual load. Soil type accounted for a variation up to approximately 40%, which can be mostly attributed to drainage. The annual nitrate leaching for forage system varied from 281 kg/ha for bermudagrass-bermudagrass-winter grains to 397 kg/ha for sorghum-millet-winter grains. Forage systems using corn, millet, and sorghum had the highest biomass accumulation followed by Bermuda grass and Bahia grass. The best forage systems to prevent

nitrate leaching were; Bermuda grass or corn in the spring-summer; Bermuda grass, Bahia grass, or corn in summer-fall; and winter forages in the winter. Systems included millet or sorghum leached the most.

The studies clearly indicate the importance of incorporating multiple factors into the development of potential BMPs. Variations in the forage system and soil can have a substantial impact in the nitrate leaching from dairy spray fields and pastures. Using long-term meteorological trends, such as the ENSO, can provide valuable economic and environmental information to be used in seasonal management of dairies and their associated BMPs.

6. *Cabrera, V.E., Breuer, N.E., Hildebrand, P.E., and Letson, D. (2005). The Dynamic North Florida Farm Model: A User-friendly Computerized Tool for Increasing Profits while Minimizing N Leaching Under Varying Climatic Conditions. Computers and Electronics in Agriculture; 49: 286-308.*

Original abstract: "This paper describes the computer implementation of the *Dynamic North Florida Dairy* farm model (DyNoFlo Dairy). The DyNoFlo Dairy is a decision support system that integrates nutrient budgeting, crop, and optimization models created to assess nitrogen (N) leaching from North Florida dairy farm systems and the economic impacts resulting from reducing it under different climatic conditions. The decision support system, based on Excel[®] and Visual Basic[®] software, responds to dairy-septic environmental (climate and soils) and managerial characteristics (livestock management, waste management, crop systems management) and can be used to study the economic and ecologic sustainability of these systems.

The DyNoFlo Dairy model is a dynamic adaptation of the framework "balance" of nutrients in dairy farms, commonly used in Florida. The DyNoFlo Dairy model incorporates Markov-chain probabilistic simulation of cow-flows and crop simulation for historical climatic years with El Nino southern oscillation (ENSO), automated optimization of managerial options, participatory modeling, and user friendliness. This paper discusses the model components and its computer implementation in a user-friendly application. The model was parameterized for conditions found in North Florida dairy farm systems. It is intended to be a tool for producers, regulatory agencies, and extension services, and because of that, participatory and interdisciplinary work was pursued during model creation, calibration, and validation. A case study for a synthesized North Florida dairy farm using the DyNoFlo Dairy model found substantial differences in the N leaching for different ENSO phases and other managerial factors; and the possibility of decreasing N leaching up to 25% while still maintaining profitability levels."

Summary of Key Findings

The Dynamic North Florida Dairy farm model (DyNoFlo Dairy) is decision support system software based in Microsoft Excel. This software takes a systems approach to simulating the North Florida dairy farms to develop the nutrient balance for the farm. DyNoFlo Dairy incorporates traditional model components, such as waste management, crop growth, and foraging. It also incorporates some novel components including economics, El Nino and La Nina climate comparisons, Markov chains for simulating the flow of cows, and an optimizer for nitrogen leaching and profit. *The Dynamic North Florida Farm Model: A User-friendly Computerized Tool for Increasing Profits while Minimizing N Leaching Under Varying Climatic Conditions* by Cabrera, et al describes the components of the DyNoFlo Dairy model and calibration and simulation results for El Nino and La Nina years. Of particular interest in this article are the results of the synthetic farm used for calibration of the model. Additionally, the model includes Linear Optimization that was used to reduce N leaching while increasing profit.

Results of the synthetic North Florida dairy farm showed several key findings. Nitrogen leaching was always lower during La Nina (dry and warm) years and higher during El Nino (cold and wet) years. Additionally, profit was inversely related to nitrogen leaching, so La Nina years had the highest profit and El Nino had the lowest profit. On a monthly basis, profit was highest between April through July that correspond to higher biomass accumulation (less leaching) and therefore profit. January appears to be the most critical month accounting for 30% and 40% of Nitrogen leaching for La Nina and El Nino years, respectively.

Four management practices in the synthetic farm were varied in the DyNoFlo Dairy model to reduce N leaching while increasing profit. These include the time amount of time a cattle is confined, the amount of crude protein in the cow's diet, the pasture forage rotation, and the spray field forage sequences. The optimizer selected management strategies included:

- Low crude protein level,
- Variable level of confined time,
- A variable forage sequence for pasture land, and
- Variable crop rotations on varying areas of the spray fields.

Cabrera, et al indicates that all the management strategies chosen by the optimizer cannot be practically implemented by dairy farmers. Feasible changes include reducing the crude protein content in the cow's diet, changing the confined time of the animals, using a constant area spray field with similar crop rotations to those found in the optimizer, and implementing the forage sequence presented above in all pastures. Using these feasible management strategies nitrogen leaching may be decreased by 23% and profit could be increased by 2.5% at the same time. Overall, the authors found:

“The most critical factor in reducing Nitrogen leaching without impacting profit is the selection of crop rotations on spray fields and pastures... Changing from the “high” to the “low” crude protein in diet can substantially decrease N flows to most spray fields.”

The authors also suggest seasonal adjustments when El Nino years are forecasted. These include:

- Reducing the number of cows through heavier voluntary culling,
- Export manure, and
- Rent additional pasture land and reduce confined time.

7. *Chrysostome, M, Nair, V.D., Rhue, R.D., Harris, W.G., and Graetz, D.A. (2003). Assessment of Vertical Movement of Phosphorus through the Soil Profiles of Manure-impacted Sites. Southern Branch ASA Annual Meeting, Feb. 1-4, 2003. Mobile, Alabama.*

Original abstract: “Soil Phosphorus (P) testing has been developed over the years to fulfill agronomic goals. However, there is no soil P test for environmental purposes. Some attempts have been made recently to use the Degree of Phosphorus Saturation (DPS), which relates a measure of P already adsorbed by a soil to its P adsorption capacity, as an environmental P test. Previous research using oxalate-extractable P, Al and Fe to calculate DPS has been successful. For Florida conditions, that is, mainly sandy soils, a method to calculate DPS using Mehlich 1-extractable P (M1-P), Al and Fe has been recently developed. This study aims at developing a method to assess P release and movement from various manure-impacted sandy soils, using a water extract and then relating the P in the extract to DPS. Soil samples were collected from four sites: two dairy areas and two poultry areas. Water Soluble P (WSP) has been determined for Ap, E, and Bt horizons, using different ratios: the conventional 1:10 soil:water ratio, 5:1, 10:3, 5:2 ratios, and a column leaching method. The DPS values showed more accurate estimation of P movement in the environment when the column leaching data were used than with the conventional method, since the P leaching method is closer to the reality than the conventional WSP determination. WSP using large soil:water ratio seemed to be better correlated to the DPS values. WSP, M1- P, and DPS showed a similar non-linear relationship with cumulative P in the columns. The relationship appeared to be of exponential type for Ap and E horizons. Continuing research will focus more on relationship differences based on horizon types.”

Summary of Key Findings

Due to the lack of soil phosphorus (P) tests for environmental purposes, the goal of this study was to relate the P results from water extract to the degree of P saturation (DPS) and develop a tool to assess P release and movement of manure-impacted sandy soils. The results of this study indicated an exponential type relationship

between water soluble P, Mehlich 1-extractable P, and DPS for the Ap and E horizons, but further research will focus on the horizon type relationship differences.

8. *Chrysostome, M., Nair, V.D., Rhue, R.D., Harris, W.G., Portier, K.M., and D.A. Graetz, D.A. (2004). Minimizing Confounding Factors in P Leaching Assessment for Dairy and Poultry Manure-amended Soils. Program and Abstracts. Sustainable Land Application Conference. January 4-8, 2004. Lake Buena Vista, Florida.*

Original abstract: "Soil Phosphorus (P) concentrations in agricultural lands have increased over the years, increasing the potential for P loss to surface waters. Soil test P (STP) methodology has been developed primarily for agronomic purposes. Attempts have been made to use the Degree of Phosphorus Saturation (DPS) as an environmental soil P test. However, DPS and conventional Water Soluble P (WSP) determinations have different relationships for dairy and poultry manure sources due to solubility differences among manure types. Our objectives were to develop parameters to characterize P leaching from dairy and poultry manure-amended soils and evaluate the relationships between them. Soil samples were collected from two dairy and two poultry sites within the Suwannee River Basin. WSP was determined using 1:10 (conventional) and 5:1 soil: water ratios. Soils in a column experiment were leached using unsaturated flow. Results showed that relationships between DPS and WSP (5:1) were consistent for dairy and poultry manure-amended soils. The 5:1 soil:water ratio, which is closer to field moisture conditions, would be a better indicator of P leaching from manure-amended soils. A paired t-test will be conducted to compare WSP methods (1:10, 5:1 and column leachates) and a correlation test will be used to measure the strength of linearity among them. A non-linear estimation program will be used to investigate the relationships among the P leaching parameters and the STP data."

Summary of Key Findings

Due to differences in solubility for different manure types, degree of phosphorus saturation (DPS) and water soluble phosphorus (WSP) have different relationships for dairy and poultry manure, thus DPS is not used as an environmental soil test. Developing parameters to characterize phosphorus (P) leaching from dairy and poultry manure-amended soils and to evaluate the relationships between them were the focus of this study. WSP was determined for samples from two dairy and two poultry operations using a conventional and a modified soil:water ratio. Column experiment results indicated that a modified soil:water ratio of 5:1, which is closer to moisture conditions in the field, was consistent with the manure-amended soil samples and would be a better indicator for these soils. Further research includes comparison of WSP methods and investigation of the relationships among P leaching parameters and soil test P data.

9. *Chrysostome, M, Nair, V.D., Rhue, R.D., and Harris, W.G. (2004). Validation of Soil Phosphorus Storage Capacity Under Controlled Conditions. ASA/SSSA/CSSA Annual Meeting, October/November 2004, Seattle, WA. (CD Rom publication)*

Original abstract: "Soil Phosphorus (P) concentrations in agricultural lands have increased over the years, extending concerns over eutrophication of surface waters. This is particularly a growing issue in the Suwannee River Basin (SRB), dominated in many parts by intensive animal agriculture. This study evaluates the effects of P loading on the storage capacity of dairy and poultry manure-amended soils. Forty soil samples, representative of A, E, and Bt horizons, were collected from two dairy and two poultry operations within the SRB. Soils were packed into a 1.5 diameter column and a solution with background electrolyte passed through the column using unsaturated flow at pore water velocities of approximately 1cm/day. Then the soils were leached with known quantities of P. P in the effluent was measured repeatedly. Mehlich 1 and oxalate extracts were analyzed for P, Ca, Al, Fe, and Mg. The P Saturation Ratio (PSR) was calculated before and after the repeated additions of P. The remaining storage capacity of the soils was calculated based on an optimum PSR of 0.15 for both Mehlich-1 and oxalate solutions. Results showed substantial reductions in P storage capacity after P additions. Reductions in P storage capacity were comparable to predicted values derived from P loading amounts."

Summary of Key Findings

Dairy and poultry manure-amended soils were used in this study to evaluate the effects of phosphorus (P) loadings on storage capacity. Soil columns representing A, E, and Bt horizons were collected from two dairy and two poultry operations. Unsaturated flow was passed through the columns and then they were leached with P. The P saturation ratio (PSR) and remaining storage capacities were calculated. Results of this study indicated reductions in P storage capacity after P additions that were comparable to predicted values.

10. *Chrysostome, M. (2005). Assessing the Vertical Movement of Phosphorus in Manure-impacted soils. PhD dissertation. Soil and Water Science Department, University of Florida, Gainesville.*

Original abstract: "Soil phosphorus (P) concentrations in agricultural lands have increased over the years, increasing the potential for P loss to surface waters and the risk of eutrophication. Sandy soils present high risks of P leaching, especially where intensive animal agriculture is taking place. The purpose of this study is to evaluate the potential for P leaching from dairy and poultry manure-impacted sites of the Suwannee River Basin. Soil samples were collected from two dairy and two poultry sites during three periods of time. Different physical and chemical characteristics of the soil were determined. The P saturation ratio (PSR) was calculated as the molar ratio of extractable P to extractable Fe and Al. The soil P storage capacity (SPSC) was

calculated using a PSR threshold of 0.15. A low soil:water ratio (5:1) was used to determine water soluble P (WSP) in order to minimize solubility differences in different manure types. For evaluation of the leaching potential in a column experiment, forty soil samples representing A, E and Bt horizons were leached using unsaturated flow. The amounts of P in the sandy (A and E) and in the loamy and clayey (Bt, Btg, etc) horizons were calculated over the three periods as well as the SPSC of the sandy horizons.

Results showed that relationships between PSR and WSP 5:1 were consistent for dairy and poultry manure-impacted soils. The 5:1 soil:water ratio, which is closer to field moisture conditions, appeared to be a better indicator of P leaching from manure-amended soils and is highly comparable to P concentrations in the column leachates. SPSC predictions of P storage capacity following P loading closely correspond to observed values, especially for low-impacted soils. The analysis of the P contents of the sandy and the loamy and clayey horizons showed increases for the low-impacted soils over the years, with corresponding decreases in the P storage capacity, probably due to intense P loadings. Statistical analysis of the SPSC of the sandy horizons showed that all the main effects and interactions were significant: time, type of operation (dairy or poultry) and impact level (minimally or highly impacted by manure additions)."

Summary of Key Findings

Sandy soils in the Suwannee River Basin (SRB) are characterized by low phosphorus (P) retention capacity and vertical movement of nutrients, potentially to ground and surface waters. Understanding the mobility of P in soil profiles in the SRB is critical due to the land application of poultry and dairy manure. This study evaluated physical and chemical characteristics of dairy and poultry manure-impacted soils in the SRB for the potential of P leaching. The P saturation ratio (PSR) for soil samples from two dairy and two poultry sites over a three month period were calculated. A soil: water ratio of 5:1 was developed to characterize the vertical movement of P to minimize the effects of the dairy and poultry manure solubility differences. To evaluate the effects of P loading under laboratory conditions, the PSR was used to calculate the soil P storage capacity (SPSC), or the amount of P that can safely be added to soil. Results of SPSC calculations using Mehlich 1 and oxalate P concentrations indicated that $SPSC_{\text{oxalate}}$ was more accurate and less conservative than $SPSC_{\text{M1}}$ because oxalate appeared to be the more powerful extractant. This study compared observed and predicted reductions in SPSC using unsaturated laboratory soil columns and found that SPSC provided a reasonable estimation of remaining soil capacity for P adsorption, especially for low-impacted soils. Because it conveys remaining capacity as well as previous loadings, SPSC would more validly indicate P loss risk than soil test P. Results also suggested that SPSC could potentially be a predictor of P that will be released from soils at excessive rates. Overall results of this study indicated the critical need to develop manure management plans that take into

account critical soil P levels and other inherent soil factors that can help or hinder P retention. This study also recommends P best management practices that truly reflect the P sources and the transport potential. Some recommended conservation measures that focus on balancing P inputs and outputs to decrease P yet still achieve efficient use of P and optimize crop yields include:

- Composting of solid manure for use outside of the manure-impacted sites
- Use of water treatments residuals
- By-products of water treatment plants
- Reducing the solubility of P

11. Cockx, E., and Simonne, H.E. (2003). *Reduction of the Impact of Fertilization and Irrigation on Processes in the Nitrogen Cycle in Vegetable Fields with BMPs. Document HS948. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville.*

Original abstract: "The nitrogen (N) cycle is a set of transformations that affect N in the biosphere. Through a series of microbial transformations in the soil, N is made available to vegetable crops. Thus, knowledge of this cycle by which N passes from air to soil to organisms and back to air, and how the components of the cycle are affected by human activities, is required to design effective strategies for decreasing undesirable losses of N from vegetable production to the environment. Adequate management of fertilization and irrigation has always been recognized as one of the keys to successful vegetable production in Florida. Thus, fertilization and irrigation practices have aimed at supplying enough nutrients and water to ensure economical yields. Since up to 200 lbs/ Ac of exogenous N are recommended for vegetable production in Florida, and fertilizer use efficiency seldom exceeds 75%, it is likely that fertilization affects the N cycle. Best Management Practices (BMPs) aim at reconciling the needs of economical vegetable crop production with those of environmental protection. Effective BMP implementation, therefore, requires an understanding of how current cultural practices affect certain processes in the N cycle in commercial vegetable fields. It is likely that a complete understanding of these issues by farmers and vegetable professionals will be a prerequisite for the success of the BMP program. The goals of this article are to (1) present the N cycle as it relates to crop production, (2) describe how fertilization and irrigation affect the processes within N cycle, and (3) explain how the proposed BMPs may help reduce the negative environmental impact of these cultural practices."

Summary of Key Findings

This document outlines the affect of vegetable production in Florida on the N cycle. The affects of fertilization and irrigation in vegetable production can be related to the dairy spray fields, as fertilization and irrigation are also occurring. The article reviews the nitrogen cycle and the affects that agricultural practices may have on the steps of

the N cycle.

The N cycle for unimpacted areas was thoroughly reviewed and divided into seven major steps, which include:

1. Conversion of organic matter to ammonium
2. Adsorption of ammonium in solution to clay particles and back into solution (mineralization),
3. Conversion of ammonium to nitrite, nitrate, or volatilized to the air,
4. Uptake of ammonium into the plant root or nitrate into the plant root, into the groundwater, or denitrified in soil
5. Dinitrogen in air to ammonia for the plant
6. Dinitrogen into fertilizer, and
7. Return of organic matter to the soil.

Agricultural practices do not alter the N cycle; however, they may change the relative importance of each step. The authors suggest the following practices affect the N cycle:

- Modifying soil microorganism population (fumigation),
- Adding N to the root zone (fertilization),
- Affecting water movement (irrigation),
- Indirectly changing the temperature (mulching),
- Indirectly changing the pH (liming), and
- Adding organic carbon source into the root zone (cover crop).

Fumigation kills nitrifying bacteria and will slow the nitrification for two to three weeks after the application of the fumigant. Fertilization will affect plant uptake rate, but also affect the rate of mineralization, nitrification, denitrification, and ammonia volatilization. Irrigation may affect the N cycle by creating anaerobic conditions in soils caused by flooding. Overabundance of water may lead to leaching of nitrogen from the soil to the groundwater. If anoxic and then dry conditions are created the Steps 2, 3, and 4 of the N cycle may be affected.

Other practices may indirectly affect the N cycle. Cover crops reduce erosion, trap residual soil N after harvest, and reduce loss of N to the environment. The use of a cover crop may also increase the C:N ratio in the soil, which will increase mineralization rates and could potentially increase denitrification.

BMPs may be developed to limit the affect of agricultural practices on the N cycle. These BMPs should focus on reducing the impact of agriculture on the N cycle, while maintaining or increasing productivity. The authors advise that "BMPs are interconnected and inseparable. They have an indirect effect on water quality. Hence, BMPs should be used together, and the weakest BMP will determine the efficiency of the entire BMP plan."

12. *Dukes, M.D., and Simonne E.H., (2005). Evaluation of Water Use and Nutrient Leaching Under High Frequency Irrigation for Use in Best Management Practices. Water resources Research center, University of Florida, Gainesville, FL.*

Original abstract: "As a result of increased competition among industrial, residential, commercial, and agricultural water users throughout Florida, much of the state will not be able to meet projected water needs in the future. Methods to optimize current uses of water including agricultural irrigation need to be developed. In addition, nitrate levels in the ground water and surface water of the Suwannee River basin have been increasing. Biological growth in the Suwannee River is limited by nitrogen; therefore, excess amounts of this nutrient input into the system results in increased growth of algae and other organisms. Much of the nitrate is believed to be a result of intense agricultural production with vegetable production being a major agricultural component of the region. The objective of this project is to assess the performance of soil moisture based drip irrigation under plasticulture on green bell pepper at minimizing irrigation water use and movement of nitrogen below the crop root zone. Soil sampling and injection of a water soluble dye will enable quantification of nutrient movement within and below the root zone and demonstrate to producers and other interested parties the movement of water within and below the crop root zone. The hypothesis is that high frequency small irrigation events will minimize irrigation water use and nitrogen leaching compared to typical practices while maintaining economical yields. There is a balance between maximizing crop yield and minimizing environmental impact. Comparisons will be made between maximum yield and minimum environmental impact."

Summary of Key Findings

"This work has had several "setbacks". Green bell peppers were transplanted on March 26, 2003. Shortly thereafter, nighttime air temperatures dipped below freezing which damaged the transplants. This caused a two week delay in normal pepper growth. The irrigation treatments were initiated after two weeks of time based irrigation to establish the plants. By early May it was clear that the automatic irrigation valves were not working properly and that the plants were stunted due to the freeze in early April. However, it is not uncommon to have to make adjustments to the valves early in the season to optimize their performance. In previous work, the valves performed the best at the middle and end of the season when water use was the greatest. In early, June several intense thunderstorms resulted in lightning strikes on the research site. This irreparably damaged the soil moisture based irrigation control valves and 8 of the buried TDR soil moisture sensors. During this same time period, there were problems with the farm irrigation system that resulted in foreign material being injected into the drip system. This resulted in uneven and unpredictable clogging of the drip tubing. As a result of this combination of setbacks, yields were approximately half typical state yields. Variation in the yield data prevented detection of statistically significant differences across the treatments. In addition, the automatically initiated irrigation treatments used more irrigation water than the

manual treatment due to valve failure in the middle of the season.”

13. *Florida Department of Agriculture and Consumer Services. (1999). Progress Report: Research, Development, Implementation, and Effectiveness of Best Management Practices to Prevent Nitrogen Contamination of Ground Water.*

Unpublished Report.

14. *Florida Department of Agriculture and Consumer Services. (1999). Status of the Nitrate Best Management Practices Program as Required by the 1994 Nitrate Bill.*

Unpublished Report.

15. *Florida Department of Agriculture and Consumer Services, and Florida Department of Environmental Protection (2005). Water Quality/Quantity Best Management Practices for Florida Vegetable and Agronomic Crops. Tallahassee, FL.*

Original abstract: Not applicable.

Summary of Key Findings

“In 2001, a Steering Committee was formed to develop this manual. This forum allowed for agricultural association groups, industry, state agencies and other stakeholders to exchange ideas in order to develop a group of practices for producers to follow to protect water resources. In general, Florida vegetable and agronomic crop producers have experienced considerable variation in the application of surface water regulations, primarily dependent upon which water management district has jurisdiction. The transient nature of many of these farms has also compounded the regulatory situation in some cases. Moreover, this segment of the industry has operated without a unified, state endorsed BMP manual. Similar BMP manuals for other agricultural operations have been in place for more than a decade, and have yielded a mature BMP program. Implementing a logical subset of practices outlined in this manual develops an industry “baseline”. This standardization of practices will identify growers who are practicing their livelihood in a sound and responsible manner. A second outcome, consistent with state law, recognizes that widespread application of BMPs provides significant reduction in pollutant loading, helping to better protect healthy waters and restore impaired waters.

This “baseline” set of BMPs is considered equivalent to the standard level of waste treatment applied to wastewater plants, industrial facilities, and/or urban stormwater systems, thus providing compliance with the Florida Watershed Restoration Act and the TMDL Technical Advisory Committee Allocation Report to the Legislature. However, in some impaired waters, additional BMPs and other treatment projects (i.e., regional stormwater treatment areas) may be needed to meet FDEP established TMDL

goals. Selecting BMPs for multiple commodities in different production regions is a difficult process. This manual uses a hierarchical approach to BMP implementation. The development of a BMP Implementation Plan rests on the following key steps:

- i. General or universal BMPs applicable to all farming operations
- ii. A decision-tree tool for additional BMP requirements
- iii. Use on-farm assessments to “fine tune” BMP plans
- iv. Development of a computer assisted, web-based system for use by growers in the future.

The following sections describe the intended application for each of the above categories. Bear in mind that education is the key factor to ensure the overall success of BMP programs. Grower training programs are also needed to ensure that BMPs are applied and implemented properly.”

Of particular relevance to nutrient management practices as they apply to vegetable and agronomic crops, this manual devotes a comprehensive chapter on the subject. The problem of nitrate contamination of groundwater resources due to improperly managed fertilization and irrigation practices is addressed in detail. The manual maintains that “the BMP approach to managing nitrogen depends on maximizing nitrogen efficiency in the production of crops so that very little nitrogen is lost to the environment.

16. French, E.C., Woodard, K.R., Graeb, D.A., Prine, G.M., and Van Horn, H.H. (1997). *Use of Dairy Manure Effluent in a Rhizoma (Perennial Peanut) Based Cropping System for Nutrient Recovery and Water Quality Enhancement. Proc. 20th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Gainesville, FL 24-26 June, 1997. IFAS Cooperative Extension Service, Special Series SS-AGR-60, Univ. of Florida, Gainesville, FL.*

Original abstract: “Development of appropriate crop management programs for dairy effluent spray fields is needed to efficiently use the available nutrients and avoid possible ground water contamination. The most desirable design for any cropping system is one that meets environmental demands by maximizing nutrient uptake by the crops while meeting the needs of dairy producers. Several cropping *systems* using traditional crops have been suggested for use under spray fields. Rhizoma (perennial) peanut (*Arachis glabrata* Benth.), a relatively new crop to Florida is currently being examined for use in effluent spray fields. Perennial peanut is a legume that produces high quality forage which can be used in a dairy cow rations as a source of protein, fiber, and other nutrients. A perennial peanut sod based system in a dairy effluent spray field may also have the potential of continuous nutrient recovery over an entire year in addition to the production of high quality forage. Being a legume, perennial peanut is normally grown with no applied N fertilizer, but when N is made available, perennial peanut will take it up from the soil and manure effluent. Perennial peanut

produces a dense underground rhizome/root system which can intercept applied nutrients.”

Summary of Key Findings

This paper investigates the choice of crops in the spray fields. This article evaluates the nitrogen and phosphorous removal using the traditional cover crops rotations of corn (C) – forage sorghum (FS) – rye (R) as compared to those using a perennial peanut (PP) crop (C-PP-R and PP-R). The study monitored the three crop rotations at the University of Florida Dairy Research Unit near Hague, Florida from March of 1993 to March of 1995.

The removal of nitrogen by crops was assessed by the dry matter yield in harvests, nitrogen removal, and phosphorus removal. Previous dry matter yields and forage percentages of individual crops in North Central Florida indicated relatively close uptake values for the all three rotations, with PP-R approximately 2% less than the other rotations, which were identical. The study used no till planting, multiple harvests, and three nitrogen treatments (360 pounds per acre, 590 pounds per acre, and 790 pounds per acres) to assess the nutrient removal of the crop rotations.

The results of the dry matter yield indicated that the rotations including PP achieved lower yields. FS resulted in a twice the dry matter yield than PP. Additionally, at higher nitrogen application rates the yield in the PP was slightly decreased. Increasing nitrogen application to corn fields however increased dry matter yield. However, no crop increased substantially indicating the optimum annual loading rate was between 360 and 590 pounds per acre.

Results of the nitrogen removal indicated that the C-FS-R crop rotation had the greatest increase in removal across all nitrogen loads. However, PP-R crop rotation outperformed the other rotations in total removal. While this crop had the lowest dry matter yield, the N percentage in forage was 250% greater than other crops, causing the greater removal. Results of phosphorus removal indicated that PP did not remove the same level of phosphorus as C or FS.

As shown in various other articles review, this article reinforces that the choice of crop cover is an important factor in controlling nitrogen leaching in North-Central Florida. Perennial peanut can provide greater nitrogen removal than traditional cover crops. However, if phosphorus is also a concern, traditional crops may provide more removal.

17. *Fraisse, C.W., Campbell, K.L., Jones, J.W., and Boggess, W.G. (1996). GIDM: A GIS-Based Model for Dairy waste Management Analysis. Proceedings of the American Water Resources Association Symposium on GIS and Water Resources. September 22-26.Ft. Lauderdale, FL.*

Original abstract: "Recent evidence that agriculture in general, and animal waste in particular, may be an important factor in surface and ground water quality degradation has induced a strong interest in nutrient management research. The presence of nitrogen and phosphorus in surface water bodies and ground water aquifers is recognized as a significant water quality problem in many parts of the world. A Generic Interactive Dairy Model (GIDM) has been developed as a tool for creating alternative dairy waste management plans and evaluating the effects of such plans on surface and ground water quality degradation. GIDM utilizes a GIS-based interface to develop field level management plans, run the GLEAMS water quality model and analyze the results obtained by means of tabular reports and thematic maps. GIDM runs on SUN SPARC stations using the ARC/INFO GIS software."

Summary of Key Findings

Geographic Information Systems (GIS) can be used to spatially represent management practices on a farm level of detail and develop field level plans. *GIDM: A GIS-Based Model for Dairy Waste Management Analysis* by Fraisse et al describes the Generic Interactive Dairy Model (GIDM), which uses GIS to develop field level plans. In this model, GIS is used to better represent and process spatial information for the GLEAMS model (Groundwater Loading Effects of Agricultural Management Systems) that simulates water quantity and quality. GIDM represents an important paradigm in modeling of BMPs, where management practices are represented spatially and variations within a dairy are accounted for.

18. **Graetz, D.A., Graham W.D., Hochmuth, G.J., Mylavarapu, R., and Dukes, M.D. (2004).** *Evaluating Effectiveness of Best Management Practices for Animal Waste and Fertilizer Management to Reduce Nutrient Inputs into Ground Water in the Suwannee River Basin.*

Original abstract: "The goal of this project was to implement BMPs at the farm level to reduce nutrient loadings to ground water from agricultural activities and to evaluate their water quality effectiveness. The information gained from this project, in conjunction with the other ongoing BMP implementation efforts, will help to fulfill the Suwannee River Partnership objectives for non-regulatory approaches for reducing nutrient loadings. This will be accomplished through verification of BMPs via pre- and post-BMP water quality demonstration monitoring, stakeholder education and information transfer, and data collection for future development of a user's tool for BMP selection and simulation. This project will consist of three separate components:

- The implementation and assessment of BMPs on a row cropping farm.
- The implementation and assessment of BMPs on a dairy farm.
- The implementation and assessment of BMPs on a poultry farm.

The objectives to meet this goal were to:

(1) Coordinate cooperative efforts to refine and evaluate agricultural BMPs that are being conducted by various agencies, agricultural interests, and universities in the Suwannee River Basin (SRB). The SRBNMWG (now the Suwannee River Partnership) includes forty-six members from Federal, State, Regional, and Local Governments as well as agriculture and other private organizations. The Partnership has coordinated efforts to refine and evaluate agricultural Best Management Practices (BMPs) by a variety of mechanisms but primarily through this Section 319 project. The Partnership began with commodity and other technical committees to outline BMP effectiveness evaluation criteria which lead to the Section 319 project proposal. During the project an interagency group has met quarterly to review data and make recommendations to refine and evaluate BMPs. In addition to the S. 319 project the Partnership has coordinated efforts through the membership steering committee, and by using Florida Department of Agriculture and Consumer Services resources to fund additional BMP Effectiveness research. The Partnership and its members will continue to refine and evaluate agriculture BMPs using computer models and additional farm specific ground water quality monitoring.

(2) Improve working relationships and partnerships among the various agencies, agricultural interests, and the universities. Ongoing process through the SRBNMWG. The Suwannee River Partnership has continued to improve working relationships and partnerships among its members which are the stakeholders in the Suwannee River Basin. The forty-six members that make up the Partnership shows the basin wide support that has been built to promote voluntary incentive-based approaches to improving water quality in the basin. The Partnership now covers the majority of the Suwannee River Water Management District area and plans are being made to expand the Partnership watershed approach to the rest of the basin in Florida as well as the Upper Suwannee River Basin in Georgia.

(3) Evaluate water quality impacts (primarily ground water) from a row cropping system, dairy farm, and poultry farm in the SRB.

This was accomplished by pre-BMP monitoring of ground waters to establish a baseline groundwater quality from traditional farming practices.

(4) Implement BMPs for a row cropping farm, dairy farm, and poultry farm in the SRB. The BMPs on the row crop farm were developed by the IFAS project team based on the fertilization and irrigation management practices recommended by the Institute of Food and Agricultural Sciences at the University of Florida.

(5) Evaluate the water quality effectiveness of Best Management Practices (BMPs) for a row cropping farm, dairy farm, and poultry farm in the SRB.

This was accomplished by post-BMP monitoring of ground waters to Evaluate changes in groundwater quality due to BMP implementation.

(6) Collect data from each system for the future development of a personal computer based user's tool for BMP selection and simulation.

Soil, crop and groundwater data were used to test and calibrate models that predict water and nitrate movement through the root and vadose zones. Two existing models, the DSSAT crop model and the Leaching Estimation and Chemistry Model (LEACHM) were used. DSSAT is a shell tool containing several crop models. Implement information sharing/ educational program(s) using IFAS extension service, Soil and Water Conservation District, and public outreach to disseminate overall environmental impact awareness, types of BMPs for agricultural practices, and the result of the BMPs being evaluated in this project. Outreach was be conducted by annual presentations (or poster) at the Suwannee Valley Education Research Center Field Day (150 - 300 people), Suwannee Valley Field and Greenhouse Vegetable Short course and tradeshow (300 - 400 people) and video/slides of the BMPs evaluated."

Summary of Key Findings

This was a comprehensive study of pre and post-BMP groundwater and soil nitrate concentrations conducted on a farm scale. The objective of this study was to document the effectiveness of BMPs under actual production conditions. Studies were conducted on a row crop, poultry, and dairy farm.

The row crop BMPs were demonstrated on a 140 acre center pivot irrigated field, which half used normal practices and half used project-selected BMPs. BMPs included:

- The reduction of fertilizer amounts,
- Improved timing of fertilizer application, and
- Irrigation was designed to better reflect environmental (ET and rainfall) and soil moisture conditions.

Without decreasing yields, BMPs resulted in a 30% reduction of fertilizer and a 20% - 30% reduction in irrigation. A 35% reduction in N losses was measured in the BMP field. However, differences in the groundwater between the farmer-managed and BMP implemented field have not been observed at the time of this report. This lack of difference may be attributed to the farmer's tendency to adopt BMPs as it became clear they did not affect his yield. Crop management guides have been developed for potatoes and sweet corn as a result of the studies activities.

The study data and results were also used to test and calibrate water quantity and N models of the crops, root zone, and vadose zone. These models DSSAT and Leaching Estimation and Chemistry Model (LEACHM) would be used to predict the response to alternative BMPs. The DSSAT crop model was used to simulate and predict N and water uptake and leaching, evapotranspiration, crop yield, and the phenological response to water and nutrient practices. LEACHM was used to predict the water/nitrogen transport within the root zone, vadose zone and into the groundwater.

The resulting models indicated rapid leaching of N, general fertilizer is removed within two to three weeks of application, by rains or over irrigation, which was also seen in the field data. Modeling suggests that irrigation could be reduced by 30% without stressing the plants. As seen in the observed data, the model predicted a 30% reduction in fertilizer for potatoes.

Alternative management practices were formulated that reduce the amount of irrigation, fertilizer application rate, and improve the timing of application. While maintaining yields, model results of the alternative practices indicated that nitrogen leaching could be reduced by up to 50%. Results of these simulations showed nitrate levels below the root zone exceed the United States Environmental Protection Agency MCL of 10 mg/L of nitrate-N regardless of the implementation of BMPs. To meet the MCL, it may be necessary to rotate crops requiring high amounts of N with those requiring low amounts of N.

BMPs for a poultry farm in the Suwannee River basin were developed by the United States National Resource Conservation Service (NRCS). BMPs developed by the NRCS included;

- providing a waste storage facility, which included storage for one complete house cleanout and composting facilities for bird mortality;
- a waste utilization plan, which provides recommendations on the amount and timing of waste application on crops; and
- fencing to keep the grazing animals from sensitive areas.

The average nitrate concentrations in the groundwater at the poultry farm have been 5 to 10 mg/L of nitrate-N, which is the lowest of the three farms. This concentration has not changed since BMPs have been introduced to the farm; however, soil nitrate concentrations have decreased. The authors believe that the decrease soil nitrate levels indicate a reduction of groundwater concentrations in the future.

Unfortunately, this study was unable to report on implemented dairy BMPs. The planning of the animal waste management system and the associated operation and maintenance plan for the Byrd Dairy was finalized in July of 2003. Therefore data was not available at the time of this report, which was published in February 2004. Some conclusions have been drawn from the analysis of pre-BMP data. The dairy had the highest concentration of nitrate in the groundwater, with an average of 20 to 30 mg/L of nitrate-N. The highest concentrations, over 100 mg/L of nitrate-N, were observed near the lagoon and a cattle feeding and lounging area. This indicates that groundwater concentrations may be slow to respond to BMPs due to the residual N in the soil. Additionally, the researchers were able to observe the nitrate concentrations in a field, which will be used as a spray field, after lagoon cleanout water was applied. Small, but consistent, increases in nitrate concentrations were observed after this

event. This indicates that the nutrient management plans will have to be followed carefully to limit impacts to the groundwater.

Sampling at five week intervals occurred at all test farms. Sampling was conducted at 50 cm intervals to a depth of 2 meters and then at 100 cm intervals until the clay layer was reached. Concentrations in the soil profile responded to fertilization and the clay layer concentrations reflected the groundwater concentration. Therefore, soil sampling was believed to provide an early warning system for potential nitrate increases in the groundwater.

This study provides excellent findings on the application of BMPs in the Middle Suwannee River basin for row crops, poultry, and dairy farms. Studies clearly showed that BMPs applied at a row crop farm will maintain yield while reducing nitrate levels (by 35%) and decreasing irrigation and fertilizer inputs. Results from models calibrated from the observed data at the row crop farm indicated that rotating crops using high and low amounts of N, in addition to BMPs, may be necessary to reach the EPA nitrate MCL limit. Soil nitrate concentrations indicate that improved waste management BMPs at a poultry farm will produce a decrease in groundwater nitrate concentrations. While dairy farm BMPs were not implemented by the end of this study, early observations indicate that due to the high residual nutrient concentrations in the soil the effect of BMPs may not be seen for some time. Additionally, due to the farms susceptibility to nitrate leaching, nutrient management plans will need to be followed closely.

19. *Harris, W.G., Nair, V.D., Rhue, R.D., Graetz, D.A., Kidder, G., and Mylavarapu, R.S. (2004). Manure Phosphorus Management for the Suwannee River Basin: A Model for Highly Leachable Soils.*

Original abstract: Not applicable.

Summary of Key Findings

This research studied the effectiveness of a model at simulating phosphorus (P) transport. In terms of protecting water quality, it is essential to predict the rate of P movement through soil. In sandy soils, the rate of downward movement of P depends on its retardation, which is controlled by adsorption/desorption (A/D) reactions. Due to poor understanding of these reactions, empirical models that employ multiple sites and multiple reactions are generally used when simulating this A/D behavior. After various model studies, this research concluded that although these models simulate P transport well, there is a need to optimize the rate coefficients for each soil and each set of conditions, which limits their use. This research used soil profiles within the Suwannee River basin to study the focus model.

20. *Harris, W.G., Nair, V.D., and Rhue, R.D. (2004). Predicting Vertical Movement of Manure Phosphorus in Sandy Soils. ASA/SSSA/CSSA Annual Meeting, October/November 2004, Seattle, WA. (CD Rom publication)*

Original abstract: "Well-drained sandy soils are vulnerable to leaching of agriculturally-applied P due to high infiltration and limited P retention capacity. A vertical pathway means that P retention capacity of subsurface horizons exerts far greater control of mobility than is the case for a surface runoff pathway. The P retention capacity among sandy soils varies enough to significantly influence environmental risks associated with leaching. Vertical P movement was assessed in 29 sandy soil profiles amended with dairy or poultry manure over a 3-year period at four application sites. Predictions of P movement were based on two approaches: (i) calculated capacity based on a P saturation threshold and (i) retardation of P movement. The capacity approach most effectively accounts for previous P loading while the retardation approach works better for phosphatic soils. Data suggest that safe 'lifespan' of a manure application site can be predicted with reasonable accuracy given sufficient knowledge of soil P retention capacity and previous loading history. Even a site with minimum previous P loading may have only a few years for safe P application. Vertical P movement continues slowly even after application ceases. Therefore, applications should be discontinued before P migration reaches the depth of concern, in order to minimize eventual elevation of solution P concentrations at that depth."

Summary of Key Findings

This study used sandy soil profiles that had dairy or poultry manure application to assess the vertical movement of phosphorus (P) using two approaches. Effectively accounting for previous P loading yielded better results with an approach that calculated capacity based on a P saturation threshold. For phosphatic soils, the alternate approach, retardation of P movement, worked better. Study results indicated that with knowledge of the soil and loading variables, a reasonable "lifespan" can be predicted for manure application sites. This study recommends that because vertical movement of P continues slowly even after application has stopped, manure applications should be discontinued before the depth of concern is reached by P migration.

21. *Harris, W.G. and Nair, V.D. (2004). Risk of Phosphate Movement from Soils in the Suwannee River Basin. Open-File Report 2004-1332. Suwannee River Basin and Estuary Integrated Science Workshop. September 22-24 2004, Cedar Key, Florida.*

Original abstract: "The karst areas within the Suwannee River Basin (SRB) are vulnerable to transport of agriculturally-applied nitrate and phosphate (P) that could potentially have ecological impacts on springs and ultimately the Suwannee River estuary. Risk of impact is heightened by karst hydrology and the sandy, permeable

nature of soils that occur above the limestone. Nutrients move vertically in these areas such that runoff-based risk assessment models are not applicable. The vertical pathway means that soil retention capacity for nutrients exerts far greater control of mobility than is the case for a surface runoff pathway. Nitrate contamination risks are particularly acute in the SRB because of minimum denitrification and very low retention by soils. Therefore, nitrate is an immediate health and environmental concern. However, excessive P application could also ultimately result in environmental problems. Phosphate is reactive with soils and its 'breakthrough' at springs would take longer than nitrate, but once it reached springs its influence would continue for a much longer time than in the case of nitrate. The degree to which phosphate is being retained in four SRB soils is being monitored over a 36-month period of manure (dairy wastewater and poultry solids) application.

Data collected thus far suggest that the safe 'lifespan' of a manure application site can be predicted with reasonable accuracy given sufficient knowledge of soil and loading variables. This lifespan is influenced by soil factors such as P retention capacity and previous loading history. Even a site with minimum previous P application may have a short safe P-application lifespan (e.g., a few years) if P retention capacity is low. Vertical P movement continues slowly even after application ceases. Therefore, applications should be discontinued before the measured P migration reaches the depth of concern, in order to minimize the risk of eventual elevated solution P concentrations at that depth. The latter requires a mindset of planning to avoid future problems."

Summary of Key Findings

In the Suwannee River Basin (SRB), soil retention capacity for nutrients controls mobility more than surface runoff due to the vertical movement of nutrients caused by karst hydrology and sandy, permeable soils above limestone. Because of the health and environmental concerns of nitrate and phosphate (P), this research monitored soils in the SRB during a 36-month period of manure application to determine the degree to which phosphate was being retained. Initial results of the research suggested that with knowledge of the soil and loading variables, a reasonable "lifespan" can be predicted for manure application sites. These results indicated that applications should be discontinued before the measure P migration reaches the depth of concern because vertical movement of P continues slowly even after application has stopped.

22. **Henderson, C.L. (1998). *What is the Perspective of Dairy Farmers in Suwannee and Lafayette Counties, and Agency Personnel Regarding the Best Management Practices being Used to Reduce the Potential of Nitrogen Contamination in the Suwannee River Basin?*; Florida State University, Reubin O'D Askew School of Public Administration and Policy. Tallahassee, Florida.**

Original Abstract: Not applicable.

This student research paper, completed to fulfill graduate school graduation requirements, discusses the perspectives of agency personnel and dairy farmers regarding best management practices (BMPs) that were being voluntarily implemented on a cost-share basis (as per the Public Law 566 Program) within the Middle Suwannee River Basin to reduce the potential for nitrogen contamination. The author contends that the perspectives of the two different groups are often misunderstood, and attempts to shed light on why the respective perspectives vary by reporting the results of two surveys that were developed and conducted by the author. The surveyed parties included dairy farmers in Suwannee and Lafayette County and various agencies (i.e., the Suwannee River Soil and Water Conservation District, the Suwannee River Water Management District, the Natural Resource Conservation Service, and the Florida Department of Environmental Protection).

Summary of Key Findings:

"The research concluded that there are some marked differences between the dairy farmers and the agencies regarding the benefits of the implementation of the BMPs. The two groups understand their own mission. Now the goal must become educating one another on what the other entity is trying to accomplish. This task can only be done through communication. This researcher believes that if both groups take time to listen to each other's goals, then every one will win. The dairy farmer's operation will be more efficient, and the agencies will have a more sound environment, which in turn makes for a wise investment of taxpayer's money.

23. Henry, G.M., DeLorenzo, M.A., Beede, D.K., Van Horn, H.H., Moss, C.B., and Boggess, W.G. (1995). *Determining Optimal Nutrient Management Strategies for Dairy Farms. J. Dairy Sci.* 78:693-703.

Original abstract: "A model for dairy nutrient management was constructed to evaluate strategies for nutrient recycling using farm-specific information. The model used linear programming to determine optimal cropping systems that used nutrients from dairy manure applied to cropland. The optimal system minimized total feed costs, including purchased commodities, based on the ability of crops to take up manure nutrients and supply forages for cow rations. Nutrient uptake requirements to meet mandated regulations were incorporated as constraints to the linear programming model and were either N or P. results from sensitivity analyses showed that rations balanced for maximum dry matter intake (DMI) versus solutions with less than maximum DMI affected the crops used in the optimal cropping system and increased feed costs. The effect was greater on feed costs at low production than high production. The value of additional acreage was lower with no minimum requirement on DMI. Winter was the limiting season for N and P recycling because of less uptake by crops. Feed costs were almost always lowered by increasing crop acreage beyond the minimum required for N recycling."

Summary of Key Findings:

The researchers involved in this work claim that the mathematical model developed by them and described in this journal article presents a framework that can be used to determine the economic impact of a nutrient recycling system on farm profitability. The authors claim that evaluating the effects of recycling nutrients on the entire dairy farm operation is important to dairy producers who face environmental regulation. The mathematical model utilizes linear programming to apply constraints to dry matter intake (DMI), while performing sensitivity analyses to model input parameters (i.e., type of dairy producer, dairy farm acreage, DMI, milk production, and crop acreage). The results of this research project indicate that the dairy nutrient recycling system, which is a procedure used to balance dairy farm nutrient inputs and outputs is complex and that many variables affect the optimal cropping system that uses nutrients from dairy manure applied to cropland. In summary, results of the application of the computer model developed by the authors include the following:

- Placing a minimum requirement on DMI changed the optimal cropping system and increased feed costs compared with allowing DMI to be selected by the model;
- For a specific dairy farm operation, best solutions occur when DMI is allowed to range between the minimum and maximum limits established for that producing dairy;
- Placing a minimum constraint on DMI as milk production increased caused the optimal cropping system to change. More crops were required to meet the herd nutrient requirements and the increases in crop nitrogen uptake requirements caused by the increase in nitrogen in cow manure; and
- Variations in cropland acreage indicated an economic benefit to increasing the cropland beyond that required to balance nutrients. This reflected the economic advantage of growing forages.

24. Herrera, D.A. (2003). *Relationships Among Mehlich 1, Mehlich 3, and Water-Soluble Phosphorus Levels in Manure-amended, Inorganically Fertilized, and Phosphatic soils*. MS Thesis, University of Florida.

Original abstract: "The use of both organic and inorganic nutrients to maximize economic returns is a common practice in agriculture production. Soil testing is a tool used to predict crop response to added P fertilizer. It is commonly perceived that high soil test P concentrations indicate high potential for off-site movement and impact on surface water quality. Mehlich-1 and -3 are common soil extractants used in the southeastern US for estimating plant nutrient availability; water-soluble P, on the other hand, reflects the P concentration in the soil but not necessarily correlated with crop response to added fertilizer. Water soluble phosphorus (WSP) may give a better indication of environmental risk. Environmental risk from phosphatic soils naturally high in P is unknown. This study was designed to determine WSP levels of phosphatic, manure amended and inorganically fertilized P-sources in soils, correlate

Mehlich-1 P and Mehlich-3 P concentrations with WSP levels in soils with different P-sources and to determine the influence of Al, Fe, Ca, Mg, and soil organic carbon (OC) on extractable P. Manure-amended and inorganically fertilized soils samples were collected from the MSRB, and phosphatic soil samples from both the MSRB and St. Johns River Basin. Mehlich-1 P was significantly correlated with WSP in phosphatic; inorganically fertilized, and manure-amended soils. Mehlich-3 P was not significantly correlated with WSP in phosphatic soils but it was in manure-amended and inorganically fertilized soils. In inorganically fertilized, although significant, correlations had a low r^2 value. No statistical difference was found on the WSP concentrations among the three P sources in soils. Soil magnesium (Mg) concentration was the inorganic parameter that best explained P variability in manure amended soils. Iron (Fe) and aluminum (Al) explained 66% and 77% of the P variability in M-1 and M-3 extractions, respectively in inorganically fertilized soils. Low WSP in phosphatic soils indicated the presence of crystalline Al-P minerals with low solubility in water. Significant difference was found ($P < 0.001$) between (WSP/Mehlich-1 P) ratio in phosphatic soils with respect to inorganically fertilized and manure-amended soils."

Summary of Key Findings

The use of nutrients to maximize economic returns in agricultural production has made it critical to identify factors contributing to potential P losses, which has commonly been evaluating soil test phosphorus (P). It has been found that a high soil test P correlates well with greater risk of off-site movement. The soil P fraction that has been considered most susceptible for offsite movement is water-soluble P (WSP), but does not necessarily correlate to the crops response to added fertilizer. P availability for crop uptake in the southeast United States is estimated using Mehlich-1 (M-1) and Mehlich-3 (M-3) soil test extractions, a test commonly used to predict crop response to P application. The purpose of this study was to develop a relationship between three P sources and the corresponding water solubilities and to estimate plant activity by determining the WSP levels in soils, correlating M-1 P and M-3 P concentrations with WSP levels in soils with different P sources, and determining the influence of Al, Fe, Ca, Mg, and soil organic matter on extractable P. Manure-amended, inorganically fertilized, and phosphatic soil samples were used for this study. Results of the analysis showed a significant correlation between M-1 P and WSP in phosphatic, inorganically fertilized, and manure-amended soils. M-3 P and WSP had a significant correlation in manure-amended and inorganically fertilized soils, but did not in phosphatic soils. Analysis did not find a statistical difference in WSP concentration for the various P sources.

25. **Hochmuth, G.J. (2000). *Nitrogen Management Practices for Vegetable Production in Florida*. Document CIR1222. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville.**

Original abstract: "Nitrogen (N) is an important element for economic vegetable production, and is especially required for successful production on all mineral-soil farms in Florida. Nitrogen is required on mineral soils because such soils are largely sandy in nature, having low organic matter content. Thus, these soils retain little N against leaching so that frequent, intense rainfall, or excessive irrigation water, can leach N from the root zone and potentially into groundwater. Nitrogen management strategies should be used on vegetable farms to maximize the chances that N fertilizer will benefit crop yields and fruit quality, while minimizing the chances that N will be lost to the environment. This publication outlines some of the major N management practices, determined from research and grower experience that can be used on vegetable farms to ensure that N fertilization results in economic vegetable production without serious negative impact on the environment."

Summary of Key Findings

This paper outlines some major N practices for vegetable production. Major practices outlined by the author in water and fertilizer management, which are believed to be applicable to Middle Suwannee River dairies, are presented below.

- Scheduling N applications to coincide with crop N need and avoiding large applications of N at any given time, part of which might be leached before being used by the crop.
- Adopting soil moisture indicator devices, such as tensiometers, or other moisture-status indicator tools.
- Scheduling water applications according to crop water needs.
- Knowing the crop nutrient requirement (CNR) for N and targeting this amount for total crop N fertilization.
- Applying N at periods during the growing season when crop N uptake is most active. Avoiding late-season applications of N when crop uptake rate from the soil is diminishing.
- Managing irrigation water properly to avoid leaching and to keep water and N in the root zone. Production of crops without irrigation is risky in Florida, not only economically but environmentally as well. Well-fertilized but drought-stricken crops will leave large amounts of unused N in the soil, subject to leaching when rain returns.
- Optimally managed irrigation will reduce the risk of N leaching and increase the probability of successful crops with the N fertilization effective programs.
- Using tissue-testing or petiole sap testing (Table 4) to monitor crop-N status and to determine adjustments needed in the N-fertilization program.

These practices represent sound water and fertilizer management practices to reduce N leaching for dairy farms. However since forage crops have a lower economic value than vegetables, not all of the practices may be economically feasible.

26. *Hochmuth, G.J., and Hanlon, E.A. (2000). IFAS Standardized Fertilization Recommendations for Vegetable Crops. Document CIR1152. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville.*

Original abstract: "This publication presents in abbreviated form the fertilization recommendations for vegetable crops based on soil tests performed by the IFAS Extension Soil Testing Laboratory (ESTL). It contains the basic information from which ESTL soil-test reports and fertilization recommendations are generated. More information on vegetable fertilization is presented in SP 170, Commercial Vegetable Production Guide for Florida."

Summary of Key Findings

Nutrients in fertilizers can leach in Florida's sandy soils and, therefore, fertilizer management procedures are needed in order to minimize the negative impact of fertilizers on the environment. This circular provides vegetable fertilizer management recommendations that were developed from research and on-farm experience. These recommendations include:

- Water management;
- Soil testing; and
- Soil-test rating level

Proper vegetable crop irrigation management allows water and nutrients to stay in the root zone, thereby benefiting crop yield and quality, and the environment. In the laboratory soil testing procedure implemented at the IFAS Extension Soil testing Laboratory (ESTL), phosphorous, potassium, magnesium, calcium, copper, manganese, and zinc are extracted from soil samples via the Mehlich-1 extractant to determine fertilization recommendations for these nutrients. In addition, liming recommendations are also developed based on the Adams-Evans lime requirement test (which implements a calibration equation for Florida soils), and the target pH for the specific vegetable crop for which the recommendation is being developed. A soil test rating level is interpreted from the Mehlich-1 extractant; the UF-IFAS interpretation of this extractant is provided in this report in tabular format, and has been verified by field research in crop fields throughout Florida. Additional tables provided in this publication address the following:

- Mehlich-1 interpretation for micronutrients in soils;
- Target pH, and recommended nitrogen, phosphorous, and potassium fertilizer rates for specific vegetable crops;
- Typical bed or row spacing for specific vegetable crops; and
- Conversion of fertilizer rates from pounds per acre to pounds per 100 linear bed feet

27. *Hochmuth, G.J., and Smajstrla, A.G. (2003). Fertilizer Application and Management for Micro (Drip)-Irrigated Vegetables in Florida. Document CIR1181. Florida*

*Cooperative Extension Service, Institute of Food and Agricultural Sciences,
University of Florida, Gainesville.*

Original abstract: "Microirrigation and fertigation refer to applying irrigation water (and) fertilizer nutrients through small emitters placed on or in the soil near the plants. Drip or trickle irrigation is a type of microirrigation where the water and nutrients are dispensed to the crop via small plastic tubes with drip-type emitters that are placed near a row of plants. Drip irrigation is an important irrigation method in many crop production areas of the world, particularly in arid areas or regions which have a high competition for available water resources. Currently, approximately 40% of Florida's vegetable crops produced with polyethylene mulch culture are irrigated with drip irrigation. Vegetable crops throughout Florida grown with drip irrigation include strawberries, tomatoes, watermelons, muskmelons, cucumbers, squash, eggplants, and peppers."

Summary of Key Findings

Drip irrigation refers to applying irrigation and possibly nutrients (fertigation) to crops through plastic tubes and drip-type emitters that are located near the plant. *Fertilizer Application and Management for Micro (Drip)-Irrigated Vegetables in Florida* by Hochmuth and Smajstrla provides an extensive review of the factors involved in the design and management of drip-irrigation systems for vegetable production. The documentation is wide ranging and presents the practical aspects of the design and application of fertilizer in drip irrigation. The benefits of drip irrigation, system design considerations, tubing type and placement, soil bedding and application of drip irrigation tubing, and the effective wetting zone are discussed. Also presented is information on preplant fertilizer, injected fertilizer, fertilizer injection calculations, nutrient injection scheduling, and situations requiring expanded or compressed injection scheduling. Additionally crop establishment, clogging control, water management in relation to fertilizer injection, double cropping, and plant tissue analysis are covered.

Drip irrigation can reduce the irrigation needs by increasing delivery efficiency by up to 80% compared to subsurface irrigation and 50% compared to overhead irrigation. Additionally, N and potassium (K) can be delivered during the season in the amounts and at the particular time needed by the vegetable. This increases efficiency of the fertilization and can lead to reduced risk of nutrient leaching and crop disease. Drip irrigation systems are expensive and require significant technical skills to design, operate, and maintain the system. However, drip irrigation is an attractive option to maintain economic yields while reducing water or fertilizer use.

28. *Hochmuth, G.J., and Jones, J. (2004). Timing of Initial Nitrogen Application Did Not Affect Potato Yield. Proceedings of the Florida State Horticultural Society, 117:52-54.*

Original abstract: "Potato (*Solanum tuberosum* L.) is an important vegetable crop in Florida and requires nitrogen fertilization for economic yields. Current nitrogen (N) recommendations call for the initial 60 to 90 lb/acre N to be applied at planting. Some commercial potato producers make the initial N application several weeks prior to planting. Early applied N will not be absorbed until the seed tuber sprouts and roots are present in the soil, but this early applied N can be subject to leaching from rain or excess irrigation between the times of application until seed piece sprouting. In the Middle Suwannee River Basin, nitrates have been found in the Suwannee River and associated springs at concentrations greater than 10 ppm nitrate-N.

Therefore, it is important to determine crop production practices which might reduce the likelihood of N losses to the groundwater. In this study, two early-N timing treatments were evaluated, 60 lb/acre N applied at planting (at planting) and the same amount of N applied at plant emergence (at emergence). Potatoes with both treatments received 15 lb/acre of starter-N banded with the seed pieces at planting. Timing of the first N application had no effect on potato tuber yield in any tuber size grade three years of trials, except for Size A tubers in 2002. In this first year of trials, yield of Size A tubers (but not total marketable yield) was greater with N application at plant emergence than with the planting N application. These results showed that the first large N application can be withheld until plant emergence, increasing the likelihood of fertilizer N being taken up by the young plant and reducing the risk of N leaching losses."

Summary of Key Findings

This study was conducted over several seasons to test the theory that the initial large application of N could be withheld until the plants had emerged and had a developing root system for N absorption and thereby minimizing potential N losses to the environment.

The fields used for this research contained Lakeland fine sand, thermic, coated, typic, Quartzipsamment. The soil was plowed and disked each year in preparation for bed formation and fumigation. Preplant soil tests showed that no P or micronutrients were needed for potatoes growing on the soil in these fields, but that K would be needed.

Two time-of-application treatments for initial nitrogen were compared: application at planting and application at plant emergence. When plants were cracking through the soil surface, all potatoes received the first application of potassium, 40 lb/acre K, by banding potassium chloride to both sides of the plant row. All fertilizers were covered by re-forming the beds with a single-disk hiller. When the plants reached 3 to 4 inches in height, the second applications of N and K were made to plants in all plots. When the plants were 4 to 6 inches tall, the final applications of N were made to plants in all plots.

At early bloom, most-recently-matured whole leaves were sampled for total Kjeldahl nitrogen analyses. Data were analyzed by ANOVA in SAS to determine significance of treatment effects.

Potato yields in all years were excellent by Florida commercial red potato production standards and no production problems or diseases were encountered in either year. N timing treatment had no effect on tuber yield in any category in any year, except for Size A tubers (the largest size category) in the first season. The yield of Size A tubers was greater with N applied at emergence compared to yield with N applied at planting. The authors conclude that waiting until potato plants have emerged to make the first main N application will not negatively affect tuber yield. In fact, waiting until plant emergence to apply N will ensure the presence of roots to absorb N and minimize the risk of N leaching to groundwater if heavy rainfall occurs soon after planting, a common occurrence in northern Florida in the late winter planting season. Therefore, best management practices should not only consider the rate of N applied but also the management of applied N.

29. Holloway, M.P., Bottcher, A.B., and Campbell, K.L. (1990). *BMPs for Mitigating Nitrate Contamination of Groundwater Under North Florida Dairies. Final Report to FL. Dept. of Environmental Regulation. 109 pages.*

Abstract and report are unavailable.

30. Holloway, M.P., Bottcher, A.B., Nordstedt, R.A., and Campbell, K.L. (1991). *BMPs for Mitigating Nitrate Contamination of the Groundwater Under Dairies. Paper No. 91-2134 in Summer Mtg. American Society of Agricultural Engineers, St. Joseph, MI.*

Abstract and Key Findings: See next bibliographical citation (No. 31).

31. Holloway, M.P., Bottcher, A.B., Nordstedt, R.A., and Campbell, K.L. (1996). *Best Management Practices for Reducing Nitrate Contamination of the Groundwater on Dairy Farms. Applied Engineering in Agriculture-ASAE. Vol. 12(2):197-202.*

Original abstract: Groundwater studies conducted in north Florida indicate that improperly managed waste from dairy farms can create groundwater nitrate pollution. A study was conducted using suction lysimeters and the CREAMS computer model to evaluate recommended best management practices (BMPs) at several dairy farms in north Florida. The BMPs were determined from a nitrogen balance to reduce the amount of nitrate leaching from the dairies while maintaining economic vitality. A complete list of BMPs is given within the article.

Summary of Key Findings

This research evaluated a number of BMPs that target the reduction of nitrate contamination of groundwater resources that lie beneath dairy farms within the Suwannee River Basin (SRB). Due to the topographical and hydrogeological characteristics of the SRB, the majority of the water that leaves the dairy compounds is through soil percolation. Seven study sites were chosen at two dairies located within the SRB to conduct the research. Suction lysimeters were used to collect water as it percolated through the soil column. These samples were analyzed to quantify the nitrate concentrations. The CREAMS computer model was used to simulate nitrate levels in water that had percolated through the soil down below the root zone. Although the CREAMS model results did not match the discrete levels of nitrate concentration collected in each water sample, the annual nitrate level trends appeared to match reasonably well. As a result, the unmodified version CREAMS computer model was used for the nitrate leaching simulations. Based upon a nitrogen balance for SRB dairies in general, it was determined that BMPs for controlling nitrate contamination of groundwater are based on rudimentary principles of nutrient balance, where the amount of nitrogen as nitrate is limited as the variance of nitrogen inputs (e.g., cow feed, inorganic fertilizer, rainfall, etc.) and nitrogen outputs (e.g., volatilization of ammonia, export in milk, leaching into groundwater, denitrification in soils, etc.). If the difference between a specific dairy's nitrogen inputs and outputs (except for leaching loss) is greater than approximately 22 pounds per acre, a nitrate leaching problem might exist.

Recommended BMPs to reduce nitrogen inputs include:

- Reducing the nitrogen levels in feed;
- Using solid separator screens to filter undigested feed for immediate re-feeding or bedding;
- Off-setting purchased feed with feeds produced on the dairy; and
- Applying smaller amounts of commercial fertilizer more often.

Recommended BMPs to increase nitrogen outputs include:

- Volatilization of ammonia nitrogen;
- Increasing the milk production of the cow herd by improving health, reducing heat stress, etc.;
- Improve the surface drainage system for pastures, hayfields, croplands, spray fields, etc., to reduce concentrated surface flow;
- Employing denitrification techniques in lagoons or waste storage ponds;
- Transporting liquid manure, scraped manure, and lagoon sludge off the dairy;
- Conducting soil, manure, and plant nutrient test on a regular basis; and
- Sealing wells no longer in use.

Other BMPs include:

- Providing a concrete floor or impermeable material on or under soil at the manure collection system;
- Having cows spend at least part of their day on the collection floor throughout the year;
- Providing artificial seals on lagoons or ponds in vulnerable soils (e.g., concrete linings with a plastic underliner);
- Minimizing high intensity areas (i.e., those with more than 3 cows per acre) to minimize nitrogen overloading on pasture grasses; and
- Using proper irrigation techniques (i.e., control rate, amount, and timing of water application) when spray field land is limited to increase crop yields and nitrogen uptake.

The collected data from the lysimeters together from the CREAMS model simulations suggest the following:

- Pastures and hayfields with no winter crops reach their maximum nutrient uptake rates quickly with a relatively low number of cows per acre. This creates a situation where the probability of nitrate leaching is high due to the crops' inability to uptake additional nitrogen.
- Proper irrigation techniques allow crop uptake to increase and nitrate leaching to decrease
- Adding winter rye to a Bermuda grass spray field decreases the probability of nitrate leaching
- Manure collection and spreading are beneficial in reducing the probability of nitrate leaching

32. *Lafayette County Soil and Water Conservation District (1995). Lafayette County Manure Spreader Demonstration Project. FDEP 319(h) Contract Number WM551; Final Report. Tallahassee, FL.*

Original abstract: "Lafayette County is a region of Karst Topography and highly permeable sandy soils and is a recharge area for the Floridan Aquifer and the Middle Suwannee River Basin. Due to the high leaching potential of the area soils and sinkholes, the aquifer is susceptible to nonpoint source pollution. This project involved the development and promotion of a manure spreader leasing program to foster improved land application of animal waste. The primary objective of the program is to reduce potential level of exposure of stockpiled dairy manure and chicken litter to rainfall and subsequent transport and contamination of groundwater via leaching or direct runoff of leachate to depressional areas and sinkholes. The materials removed (primarily dairy waste) are in a form that is not easily spread by traditional equipment. The agricultural producers and the local SWCD noted that there is a need for equipment that can handle wet manures that a 60-70 horsepower tractor can power. The spreader is made available on a lease basis. By providing such

equipment environmental conditions will improve through the more timely dispersal of manures on agronomic fields based on current nutrient management recommendations by IFAS and NRCS.”

Summary of Key Findings

The Lafayette County area is overlain by highly permeable sandy soils and is a recharge area for the Floridan Aquifer. As of September 1995, there were 25 dairies operating in Lafayette County with approximately 400 cows per dairy. In addition, there were also 120 chicken houses with approximately 20,500 chickens per house. Studies had determined that a potential existed for migration to the Floridan Aquifer of stormwater runoff containing nitrates after contact with dairy and poultry farm waste material. The BMP demonstrated during this 319(h) Program project consisted of the purchase and use of a Model 455 John Deere Manure Spreader that enabled the spreading of wet cow manure and chicken litter. This BMP was deemed an alternative to stockpiling cow manure and chicken litter after sand entrapment using US Soil Conservation Service designed management systems typically used by dairies in Lafayette County. The Spreader was made available through a lease agreement to all farmers and citizens with a need to spread material from sand traps, lagoons, and high intensity areas.

33. Lubell, M. (2004). *Collaborative Watershed Management. Final Report. Dept. of Environmental Science and Policy, University of California – Davis.*

Original abstract: “To date, research on collaborative watershed management has paid scant attention to the role of grassroots stakeholders, who are the people that actually use natural resources. This paper argues cooperation from grassroots stakeholders is necessary for the success of collaborative management, and outlines three theoretical perspectives to explain cooperation. The validity of these theoretical perspectives is tested using a survey of farmer participation in the Suwannee River Partnership in Florida. The findings suggest farmers’ perceptions of policy effectiveness are largely driven by economic considerations, while participation in collaborative management is linked to social capital.”

Summary of Key Findings

“The results of the analysis suggest the view from the grassroots has important implications for several aspects of collaborative management. Most importantly, the author’s central argument is that collaborative management requires cooperation from grassroots stakeholders. Cooperation entails a behavioral component of participation in a collaborative partnership or other watershed management activity, and attitudinal support for particular sets of policies. Cooperative attitudes and behaviors are both necessary, but not sufficient to produce cooperation in the context of collaborative management. For farmers, participation is driven largely by expectations of reciprocity from other farmers and trust in local government agencies. Once

participation is secured, cost considerations and social values become more important in how they view the effectiveness of various policy options. In the context of collaborative management, there should be an early emphasis on social capital, followed by a demonstration of cost-effectiveness, and information and cost-share provisions from local agencies.

Evaluations of equity and efficiency are also affected by these results. Partnership (and survey) participation is skewed towards larger and more economically viable farms. Hence, many smaller farms may not contribute an equal amount of effort to partnership activities. If all farms contribute a fairly equal amount of nitrates to the Suwannee basin, then the larger farms might complain about an unfair distribution of costs. However, they may also be willing to tolerate free-riding from smaller farms in order to secure the benefits of cooperation—Olson (1970) might call the larger farms a privileged group. But the distribution of effort might seem more equitable if larger farms also contribute a disproportionate amount of nitrates to the river. Evaluating the equity of equal versus proportionate levels of cooperation is a venerable dilemma in distributive justice (Hardin 1982), and may even be impossible to solve even with perfect information about the nitrate runoff from every farm.

Efficiency evaluations must take into account the appropriate balance between private conservation expenditures and public cost-share money. Clearly, cost-share money is an important motivation when farmers choose among alternative BMP strategies. Some environmentalists would argue that farmers should pay for all of the conservation measures, while some conservatives would argue the public should pay for everything. Striking a balance between these two extremes must include an evaluation of how much conservation is achieved for each dollar of cost-share money. That evaluation should include not only a technical assessment of BMP effectiveness, but also the increased motivation for BMP adoption that cost-share money provides.

The motivating role of local government trust highlights the importance of intergovernmental politics. The interaction between grassroots stakeholders and local government agencies is one important nexus for securing cooperation. These local agencies essentially act as mediators between the grassroots stakeholders and the broader intergovernmental milieu. In the Suwannee case, the broader intergovernmental milieu includes regulatory agencies like the EPA and FLDEP that are generally not trusted by farmers. Hence, the first step is for the local agencies and the regulatory agencies to coordinate their goals and policies in a mutually acceptable manner. The intergovernmental coordination would include integration of legislative and judicial standards into coordinated programs. The local agencies then become vectors for delivering policy information to grassroots stakeholders, and are more effective at securing cooperation. If the FLDEP approaches a farmer and says, “To meet water quality objectives, you need to implement BMP on your farm”, the farmer is more likely to resist. However, if the local conservation district or Suwannee River

Water Management District approaches the farmer with the same plea, it is more likely to work.

Lastly, collaborative management requires feedback about the effectiveness of policy implementation activities for solving water problems, and mechanisms for adjusting policies in light of new information. Uncertainty about effectiveness decreases as the focus of inquiry moves along a chain of causality from attitude change, to behavior, to environmental outcomes. If one observes positive attitudes towards BMP, there is no guarantee that cooperative behaviors will ensue. Similarly, if one observes cooperative behavior, there is no guarantee that environmental outcomes will improve. The cooperative behaviors, for example the types of BMP implemented on the farms, may not have a large effect on environmental outcomes. Hence, the scope of inquiry in this analysis is necessarily limited, and more research effort is needed to understand the links between attitudes, behaviors, and putting effective conservation practices on the ground. Interestingly, the "reasonable assurance" concept embedded in the Florida water code reflects this uncertainty as applied to the Suwannee. Currently, the reasonable assurance documentation is based on estimates of farmer participation in the partnership. For the Suwannee Partnership to become a sustainable experiment in collaborative management, reasonable assurance will have to become more focused on watershed outcomes as BMP and monitoring technology diffuses and matures."

34. *Macoon, B., Woodard, K.R., Sollenberger, L.E., French, E.C., Portier, K.M., Graetz, D.A., Prine, G.M., and Van Horn, H.H. (2002). Dairy Effluent Effects on Herbage Yield and Nutritive Value of Forage Cropping Systems. Agronomy Jour. 94:1043-1049.*

Original abstract: "The utilization of dairy waste effluent provides nutrients and water for crop growth and allows producers to comply with regulations governing on-farm recycling of nutrients. Dry matter (DM) yield and nutritive value were measured for forages from five year-round cropping systems at effluent N rates of 450, 675, and 900 kg ha⁻¹yr⁻¹ during 4 year on a Kershaw fine sand (coated, thermic Typic Quartzipsamments) in northern Florida. Cropping systems were rye (*Secale cereale* L.) grown in tandem with either Bermuda grass (*Cynodon* spp.), corn (*Zea mays* L.)-Bermuda grass (CBR), corn-forage sorghum [*Sorghum bicolor* (L.) Moench; CSR], rhizome peanut (*Arachis glabrata* Benth.; PR), or corn-rhizoma peanut (CPR). Annual yields increased with N level in Years 1 and 2, but not during Years 3 and 4. Yields were similar among BR, CBR, and CSR (25.9 mg ha⁻¹) in Year 1. In Year 2, BR (31.2 MG ha⁻¹) had the greatest yield followed by CBR and SCR (avg. 25.5 Mg ha⁻¹). In Years 3 and 4, yields of BR (21.1 MG ha⁻¹) and CBR (20.7 MG ha⁻¹) declined while yield of CSR remained constant. Systems CPR and PR yielded less during the 4 year (17.6 Mg ha⁻¹). In vitro digestibility of BR (580 g kg⁻¹) was lower than for the other systems (mean of 653 g kg⁻¹). Cropping system had a major impact on forage yield and nutritive value, but N rates above 450 kg ha⁻¹ had relatively little effect on these responses."

Summary of Key Findings

This study set out to examine commonly grown crops in north-central Florida and evaluate them under effluent application to examine nutrient capture and forage production potential. The authors analyzed dry matter (DM) yield, crude protein (CP) concentration, in vitro organic matter digestibility (IVOMD), and neutral detergent fiber (NDF) concentration of forages from five year-round cropping systems irrigated with dairy waste effluent at three levels of N application.

The study was conducted for four 12-month cropping cycles (years). Treatments were assigned to a split-plot experiment in a randomized complete block design with three replications. The effluent was pumped directly from a lagoon system. All five cropping systems evaluated had rye as the common cool-season crop. Two of the cropping systems consisted of a single forage as the warm-season component, namely Bermuda grass or rhizoma peanut. The other three systems had crop rotations based on corn as the first crop of the season. These were corn-Bermuda grass, corn-sorghum, and corn-rhizoma peanut. Responses were analyzed by fitting mixed effects models using the PROC MIXED procedure of SAS.

The differences in total annual yield among cropping systems were due largely to differences among the warm-season crops within each cropping system because there were no differences in rye yields among cropping systems. The cropping systems based on rhizoma peanut were lowest yielding. Yields were similar among BR, CBR and CSR in Year 1, greater for BR than CBR and CSR in Year 2, then greater for Years 3 and 4 were likely due to the decline in yield of systems including Bermuda grass.

For cropping systems in which corn was the first crop, it was evident that differences in yields among systems were mostly due to contribution of the second crop. Between the second crops in the corn-based systems, yield of Tifton 85 Bermuda grass was greater than yield of sorghum in Year 1, but in subsequent years, sorghum had greater yields than Bermuda grass.

Like with the DM yield data, the differences in annual CP concentration among cropping systems were due largely to the warm-season components. When rhizoma peanut or Tifton 85 Bermuda grass were the sole warm-season crops in a cropping system, CP concentration was superior to the other cropping systems. In all years, the PR system had the highest CP concentration among cropping systems, followed by the BR system, and the CSR system had the lowest CP. Although differences in CP were evident, the contribution of rye to differences in annual average CP concentration among cropping systems was minimal because of the low DM contribution from the rye.

The annual average forage IVOMD of the BR and CPR systems responded to effluent N application, but there was no response from the other cropping systems. Although differences due to effluent N were detected, they are probably too small to have a major effect on animal performance.

The data suggests that the differences in IVOMD among cropping systems were largely due to differences among the warm-season crops. For the warm-season component of the cropping systems, the pattern of IVOMD response was similar to that observed for the total system. The BR system always had the lowest IVOMD. Ranking of the systems varied, but CPR was consistently high and PR was high in all but the last year.

All systems but BR showed a decrease in annual average NDF with each subsequent year, and the responses of CSR and CPR were not the same for all years. Annual NDF was similar among effluent N levels in Year 1 but decreased in subsequent years with increasing effluent N level. There were no differences among cropping systems within years for NDF of rye.

Digestibility was lowest and NDF highest when Bermuda grass was the sole warm-season crop. Inclusion of corn in rotation with Bermuda grass improved IVOMD and reduced NDF, but lowered the CP concentration. Corn grown with rhizoma peanut result in lower CP concentration and increased NDF concentration of the cropping system, but IVOMD of the system remained similar to rhizoma peanut grown as the sole warm-season crop. Thus, systems based on Bermuda grass yielded as much and have higher CP than those based on warm-season annuals, and the IVOMD of annual forages is likely to be greater. However, the choice of cropping system ultimately will be determined by its ability to minimize nutrient losses and provide satisfactory returns to the producer.

35. *McKinnie, F.W., Graham, W.D., Jones J.W., and Graetz, D.A. (2003). Modeling and Monitoring the Water and Nitrate Transport and Potato Growth at a Vegetable Farm in the Suwannee River Basin, FL. American Society of Agricultural and Biological Engineers, St. Joseph, MI. Paper number 032127 presented at the annual meeting.*

Original abstract: "The ultimate goal of this research was to develop Best Management Practices (BMP) to reduce nutrient loadings to ground water from vegetable farms in the Suwannee River Basin. To achieve this objective nitrogen and water movement through the vadose zone was monitored and modeled under one 56.7 ha center pivot at a 2020 ha vegetable farm just west of O'Brien, FL. This farm lies just a few miles from the Suwannee River in the upstream direction of groundwater flow. The sandy soils on this farm are extremely susceptible to leaching nitrogen through the soil and then into the Floridan Aquifer. Monitoring wells, soil samples, and plant samples were used to obtain onsite nitrogen, plant and soil moisture information over time to

track nitrogen movement and calibrate mathematical models. Soil analysis, crop management and weather information provided inputs necessary for existing vadose zone and crop models. The DSSAT35 crop model and the HYDRUS2D vadose zone model were used to produce an estimate of the load and concentration of nitrogen and the quantity of water leaching through the vadose zone to the Floridan Aquifer. The DSSAT model was also used to predict crop growth, nitrogen uptake and crop yield. The DSSAT model was calibrated using the spring 2002 potato crop. The results from DSSAT were used to predict nitrogen leaching and crop yield to aid in the development of the BMP. Results from the 2002 calibration illustrate the importance of incorporating multi-dimensional water and nutrient transport and the need to replace or improve upon the current methods implemented by the DSSAT plant model.”

Summary of Key Findings

A joint research project was formed involving the University of Florida, Suwannee River Water Management District, Florida Department of Consumer Services, and Florida Department of Environmental Protection to determine the possible sources of nitrogen loads to the Middle Suwannee River basin. The research documented in this paper focused on developing an accurate model of the growth and nutrient cycle of a 2,020 row crop farm in the Middle Suwannee River basin. Previous studies have indicated potato crops may contribute a large cumulative load of nitrogen to the ground water due to sandy soils of the basin and relatively recovery of applied nitrogen (Albert 2002). Therefore, the Spring 2002 potato production on the 2,020 acre farm, which was previously studied by Albert (2002), was monitored extensively, including crop management, soil samples, plant samples, and weather data. The DSSAT35 crop growth model, developed by International Benchmark Sites Network for Agrotechnology Transfer, was created to predict crop growth, nitrate leaching, and ultimately assess the impact of new BMPs on the site.

The results of DSSAT35 model initially showed fairly accurate results of soil moisture, nitrate concentration (especially at a depth of 0-15 cm), but under predicted tuber yield and leached nitrogen substantially. The error was believed to be caused by the nitrate moving through the soil layer at a quicker rate than the model predicted. This model error most likely was the result of the DSSAT35 model assumption a flat field and 1-Deminsonal groundwater transport, when in reality the crops were planted in raised beds. To investigate this modeling error the HYDRUS2D model, a 2-Deminsonal soil-water flow and nutrient transport model, was used to simulate water and nutrient transport in the raised potato beds.

The HYDRUS2D was created using the soil information determined by monitoring in this study and in Albert (2002). Using the same initial conditions applied in the DSSAT35 model the nitrate and water movement was simulated. The results of the HYDRUS2D model indicated nitrate movement was primarily vertical through the bed at the application area and not distributed across the row. These results indicated

the DSSAT35 model should be modified to reduce the amount of area the potato crop was allowed to use. The amount of soil volume was reduced by 50%, while the amount light interception was retained. Additionally, the SCS curve number was increased to account for the increased runoff due to plant canopy and bed slope in the reduced model area.

Results indicate that the modified DSSAT35 model adequately predicts the growth and nitrate leaching of the potato crop. Overall the model continues to accurately predict soil moisture, has improved prediction of nitrate concentration, and predicts growth and leaching significantly better. However, due to the modifications to the DSSAT35 model additional data needs to be collected to validate the calibration of the model.

Once validated, the DSSAT35 model is capable of simulating various BMPs to determine their effectiveness. Several key findings for modeling of BMPs and potato crops in the Middle Suwannee River basin are presented below.

- Sandy, high infiltration soils need to be modeled with care. A good calibration to soil moisture may not correlate to a good representation of infiltration.
- A robust, 2-Dimensional model will most likely be required to simulate water and nutrient movement on irregular boundaries, such as row crop beds.
- If a combined DSSAT35 and HYDRUS2D model (a model containing both robust plant growth simulation and 2-D soil water simulation) the spatial variability of effective rainfall between the bed and furrow should be evaluated. However, this type of model may simulate the system in a more accurate manner.

36. *Nair, V.D., Graetz, D.A., Harris, W.G., Kidder, G., Mylavarapu, R.S., Rhue, R.D., and Truman, C.C. (2001). Florida Phosphorus Index Applied to Soils With High Phosphorus Risk. ASA/SSSA/CSSA Annual Meeting Abstracts. 2001. (C.D. Rom publication).*

Original abstract: "The generic P-Index and the P-Indices developed in many states do not place importance on the leaching potential of a soil as part of the 'transport characteristics' of a site. Leaching is however, a major concern in Florida due to the prevalence of gentle slopes and sandy soils with high infiltration rate, high hydraulic conductivity, and low P retention capacity. The Florida P-Index incorporates a leaching potential criteria ranging from very low (0) to very high category (8). The criteria are based on the presence of a loamy or clayey layer, the thickness and depth at which the loamy or clayey layer appears, and takes into consideration the percentage of observations that have the above characteristics within 2 m of soil depth. We are applying the Florida P-Index to two poultry and two dairy operations on sandy soils in the Suwannee River Basin which have considerable risk for P leaching. The poultry sites have land-application of poultry waste on pasture or hay fields. One

of the dairy pastures has spray field irrigation, while the other is a site for the installation of a new spray field irrigation system. Our preliminary results suggest that modifications of the P-Index will have to be made to incorporate ground penetrating radar (GPR) information particularly for soils with high or very high leaching potential."

Summary of Key Findings

Sandy soils from poultry and dairy operations that have land-application of waste and spray field irrigation, respectively, were used in this project to analyze the P-Index. Preliminary results of this project indicate that in order to incorporate ground penetrating radar information, modifications will have to be made to the P-Index.

37. *Nair V. D. and Graetz, D.A. (2002). Dairy Effluent and Cropping System Effects on Degree of Phosphorus Saturation and Leaching in Soils of the Middle Suwannee River Area.*

Original abstract: Not applicable.

Summary of Key Findings

Although originally designed for crop production, soil fertility tests for phosphorus (STP) are being used in Florida for environmental evaluation of P saturation. By relating the extractable P concentration in a soil to its P sorbing capacity, known as the Degree of P Saturation (DPS), an indication of the P likely to be mobilized from a soil is obtained. The objectives of this research were to use different calculation methods to determine DPS, relate manure-impacted soil DPS values to water extractable P, and to evaluate the relationship of soil test P and DPS. Analysis of the soil profiles for this research included soil characterization, sorption capacity of the soil, and DPS calculation.

38. *Nair, V.D. and Graetz, D.A. (2002). Threshold Degree of Phosphorus Saturation (DPS) for Florida's Sandy Soils. Soil and Water Science Department, University of Florida. Research Brief. SWS 02-03. <http://soils.ifas.ufl.edu/departments/briefs/sws02-03.pdf>*

Original abstract: Not applicable

Summary of Key Findings

Although originally designed for crop production, soil fertility tests for phosphorus (STP) are being used in Florida for environmental evaluation of P saturation. By relating the extractable P concentration in a soil to its P sorbing capacity, the Degree of P Saturation (DPS), indicates the P likely to be mobilized from a soil. For research purposes, soils profiles from four manure-impacted and four non-impacted dairy sites were evaluated. DPS values were calculated using three methods, DPS_{Ox} and DPS using Mehlich 1 (DPS_{M1}) and Mehlich 3 (DPS_{M3}). These values were then related to

water soluble P (WSP). This research indicated that if a 25% DPS value is used is a critical DPS values for Florida soils, a large percentage of manure-impacted surface soils are potential risks to water quality. This research also suggests a desirability to replace STP with DPS_{MI} as the indicator of P release potential in Florida's P-Index. This replacement is suggested because of the availability of DPS_{MI} in soil testing programs in Florida, in addition to the literature evidence for 25% DPS as the critical value for environmental risk.

39. *Nair, V.D., Graetz, D.A., and Walker, M.L.(2002). Degree of Phosphorus Saturation (DPS): An Indicator for Predicting Water Quality Degradation. In Abstracts Volume IV. 17th World Congress of Soil Science. Bangkok, Thailand. August 14-21, 2002.*

Original abstract: "The need for an indicator to assess the potential of phosphorus (P) moving from the site of its intended use to surface waters either via surface runoff or subsurface drainage is critical. The 'Degree of P Saturation' (DPS), which relates a measure of P already adsorbed by a soil to its adsorption capacity, could be a good indicator of that soil's P release capability. The sandy soils of the Suwannee River and Lake Okeechobee Basins in Florida, USA, which receive significant loadings of animal manure, and have the potential for subsurface P movement, are ideal testing sites for the DPS indicator. Various farmer-owned sites were selected within the basins and four soil profiles were obtained from each site. The soil samples were divided by horizon and DPS was determined for each horizon using different methods.

While several methods of DPS determinations produced positive results as good indicators, determining DPS as a function of Mehlich 1-P and the sum of Mehlich 1 (Fe+Al) seemed to be the most practical one for calculating DPS for the sandy soils of Florida. A linear relationship between DPS values and water soluble P indicates that DPS could be used in a routine manner for 'environmental soil testing' in watersheds impacted by organic fertilizer applications. The information obtained from this study allows identification of soils and landscapes where application of excessive amounts of manure P may result in degradation of nearby bodies of water, even in the absence of soil erosion hazards. A threshold DPS value needs to be identified so as to assess the 'life' of a soil for continued P addition without detrimental effects to water quality."

Summary of Key Findings

This research divided soil profiles from farmer-owned sites within the Suwannee River and Lake Okeechobee Basins by horizon and determined the degree of phosphorus saturation (DPS) for each horizon using different methods. Results of this analysis found several methods that yielded good results but in terms of sandy soils, the most practical method for determining DPS is a function of Mehlich 1-P and the sum of Mehlich 1 (Fe+Al). The results of this study soils and landscapes that may result in degradation of nearby waterbodies can be identified.

40. Nair, V.D., Graetz, D.A., and Walker, M.L. (2002). *Degree of Phosphorus Saturation (DPS): An Indicator for Predicting Water Quality Degradation. Paper 222. p 222-1 to 222-9. Transactions. World Congress of Soil Science. Bangkok, Thailand. August 14-21, 2002. CD Rom publication.*

Original abstract: "The need for an indicator to assess the potential of phosphorus (P) moving from the site of its intended use to surface waters either via surface runoff or *subsurface drainage* is critical. The 'Degree of P Saturation' (DPS), which relates a measure of P already adsorbed by a soil to its adsorption capacity, could be a good indicator of that soil's P release capability. The sandy soils of the Suwannee River and Lake Okeechobee Basins in Florida, USA, which receive significant loadings of animal manure, and have the potential for subsurface P movement, are ideal testing sites for the DPS indicator. Various farmer-owned sites were selected within the basins and four soil profiles were obtained from each site. The soil samples were divided by horizon and DPS was determined for each horizon using different methods.

While several methods of DPS determinations produced positive results as good indicators, determining DPS as a function of Mehlich 1-P and the sum of Mehlich 1 (Fe+Al) seemed to be the most practical one for calculating DPS for the sandy soils of Florida. A linear relationship between DPS values and water soluble P indicates that DPS could be used in a routine manner for 'environmental soil testing' in watersheds impacted by organic fertilizer applications. The information obtained from this study allows identification of soils and landscapes where application of excessive amounts of manure P may result in degradation of nearby bodies of water, even in the absence of soil erosion hazards. A threshold DPS value needs to be identified so as to assess the 'life' of a soil for continued P addition without detrimental effects to water quality."

Summary of Key Findings

Because of the concern about the environmental fate of phosphorous (P), the development of ways to manage nutrients from animal wastes in order to minimize environmental risks is needed. Several methods of soil test P are useful under surface erosion and runoff conditions. However, in sandy soils characterized by vertical movement, relating the measure of P already adsorbed by a soil to its adsorption capacity, degree of P saturation (DPS), could indicate the soil's P release capability.

The objectives of this research were to use different calculation methods to determine DPS, relate manure-impacted soil DPS values to water extractable P, and to evaluate the relationship of soil test P and DPS. For this study, soil profiles from farmer-owned dairy pastures and unimpacted soils in the Lake Okeechobee and Suwannee River Basins were used. Analysis of the soil profiles for this research included soil

characterization, sorption capacity of the soil, and DPS calculation. A good relationship among the DPS determination methods allowed comparison of the original methodology to one more practical in Florida, where the most common soil test P is Mehlich 1 (DAP). This research found that a function of Mehlich 1-P and the sum of Mehlich 1 (Fe+Al) is the most practical method for determining DPS in sandy soils. This research also found that DPS would be a good indicator of potential release P throughout the profile because for manure-impacted soils, DPS values are highly correlated to water soluble P.

41. Nair, V.D., Graetz, D.A., Walker, M.L., and Portier, K.M.. 2002. *Threshold Degree of Phosphorus Saturation for Florida's Sandy Soils. ASA/SSSA/CSSA Annual Meeting Abstracts. 2002. C.D. Rom publication.*

Original abstract: "The need for an alternate indicator to traditional soil test P to assess the potential of P moving from a given site to surface waters via surface runoff or subsurface drainage is critical. The degree of P saturation (DPS) that relates a soil's extractable P to its P sorbing capacity would likely be an indicator of the P that will be mobilized from a soil system. Soil samples were collected from several manure-impacted surface and subsurface sandy soils in the Suwannee River Basin, Florida. We determined DPS as the percentage of oxalate-extractable P to the sum of oxalate-extractable Fe and Al (DPSOx) and compared the results with DPS calculated using Mehlich 1 (DPSM1) and Mehlich 3 (DPS M3) as the extractants for P, Fe, and Al. In all three cases of DPS calculations, it was noticed that the relationship between water soluble P (WSP) and DPS has an abrupt slope change at about 20% DPS (DPSOx = 20.1, CI= 16.6 to 23.7; DPSM1 = 19.8, CI=10.2 to 29.4; DPS M3 = 16.4, CI=11.8 - 20.9). These values agree well with weighted DPSOx > 25% being identified in the Netherlands as contributing to ground water pollution with P. If DPSOx=25% is taken as the threshold DPS value, then almost all surface manure-impacted soils (n= 72) and 20% of the subsurface soils (n= 254) that we evaluated will be an environmental concern."

Summary of Key Findings

This research examined the degree of phosphorus saturation (DPS) as it relates to the amount of P mobilized from soil. DPS values were analyzed for soil samples from manure-impacted surface and subsurface sandy soils. The DPS calculation results from this study corresponded with previous research results. In addition, if the DPS value calculated in this study is used as the threshold value, a majority of the soils tested are an environmental concern.

42. Nair, V.D., Rhue, R.D., Harris, W.G., and Graetz, D.A. (2002). *Depth Evaluation of Phosphorus Loading in Leaching Assessment of Manure-amended Soils. ASA/SSSA/CSSA Annual Meeting Abstracts. 2002. C.D. Rom publication.*

Original abstract: "Vertical movement of phosphorus (P) is an important transport pathway in some sandy soils. It is necessary to account for the depth of elevated P concentrations from previous loading to predict subsequent available P retention capacity of a given soil volume. Risk assessment of P for leaching-prone soils requires that a valid and practical indicator of the affected depth be included in the assessment protocol for nutrient management using the P Index. Several approaches to determine depth to background P levels were evaluated, including a 'quick P test' which can be conducted directly in the field, conventional Mehlich 1 soil P, and degree of P saturation (DPS). The 'quick P test' involves testing a small amount (less than 0.5 g) of soil with reagents used in the phosphomolybdate blue colorimetric method for P determination. Calculation of DPS makes use of P, Al, and Fe determined in the same Mehlich 1 extraction. Analyses were conducted by 5-cm depth increments and by horizon for two dairy spray fields and two poultry manure application sites. Results show that the 'quick P test' and Mehlich 1 P correspond very closely, and indicate similar depth to background levels. Values of DPS also showed similar trends with depth. Data show that the 'quick P test' will be a reliable and practical field indicator of depth to background P concentrations."

Summary of Key Findings

This research used soil from two dairy spray fields and two poultry manure applications sites to evaluate methods of determining the depth to background phosphorus (P) levels; methods used included a 'quick P test,' conventional Mehlich 1 soil P, and degree of P saturation (DPS). This research found similar depth to background levels for the 'quick P test' and Mehlich 1 P. In addition, for field indication of depth to background P concentrations, 'quick P test' will be reliable.

43. *Nair, V.D. Harris, W.G. and Graetz, D.A. (2003). Predicting the Safe Phosphorus Storage Capacity of Sandy Soil Profiles. ASA/SSSA/CSSA Annual Meeting, November 2-6, 2003. Denver, CO. (CD Rom Publication).*

Original abstract: "Standard soil test extraction methods (e.g. Mehlich 1) have been adapted for protocols assessing environmental risks of phosphorus (P) loss from soils. However, a low Mehlich 1-P does not indicate that the soil has the capacity to retain significant amounts of P added as fertilizer or animal waste. Spodosols of the Lake Okeechobee basin for example, if not previously loaded heavily with P, would have a low fertility index risk rating at the outset, but would quickly reach high-risk levels with P loading due to low retention capacity. We assessed the remaining P capacity of soils under dairy operations in the Suwannee River and the Okeechobee Basins of Florida by calculating of the ratio of extractable P (Mehlich 1-P) to the sum of Mehlich 1-(Fe+Al). We assumed a theoretical value of 0.15 as the maximum safe saturation capacity of a soil, the remaining capacity for a given soil layer can be calculated as $(0.15 - \text{measured ratio}) * (\text{Fe} + \text{Al})$, where Fe and Al are Mehlich 1-extractable iron and aluminum. The 0.15 maximum capacity ratio has been calculated based on earlier

research on Florida soils. The remaining capacity of a soil (mg P kg^{-1}) may then be converted to kg P ha^{-1} or in pounds acre $^{-1}$ by taking into consideration the bulk density of a soil (we have taken an average value of 1.5 g kg^{-1}) and the depth of the surface horizon (currently taken as 15 cm). A greater depth range could be accounted for in soils where leaching is >> surface runoff."

Summary of Key Findings

Although the Mehlich 1 standard soil test extraction method has been adopted as protocol for assessing phosphorus (P) loss from soils, the soils ability to retain P added as fertilizer or animal waste is not indicated by a low Mehlich 1-P value. This presentation described the methods used to assess soils from dairy farms in the Suwannee River and Okeechobee Basins for their remaining P capacity.

44. *Nair, V.D., and Graetz, D.A. (2004). Agroforestry as an Approach to Minimizing Nutrient Loss from Heavily Fertilized Soils: The Florida Experience. Agroforestry Systems, Volume 61, Numbers 1-3, pp. 269-279(11).*

Original abstract: "Nutrient buildup in the soil caused by increased animal manure and fertilizer use in agricultural and forestry practices may increase the potential for their loss from the soil, leading to groundwater contamination and non-point source pollution. Studies in the tropics have suggested that agroforestry practices can reduce such nutrient (especially nitrogen) losses because of enhanced nutrient uptake by tree and crop roots from varying soil depths, compared to more localized and shallow rooting depths of sole crop stands. In temperate systems, such benefits have been well documented for riparian forest buffer practices. Currently, other temperate agroforestry practices are also being considered for their potential to reduce runoff and leaching of chemicals and thereby improve environmental quality within the agricultural landscape. In this regard, the 'Florida P-Index,' which considers both phosphorus transport characteristics and management practices, may be a useful tool in the evaluation of nutrient management practices and environmental benefits of agroforestry.

Preliminary results from an alley cropping site and a silvopastoral site on two different soil types in Florida suggest that both of these agroforestry practices will likely reduce nutrient loss compared to conventional agricultural practices. The primary aspects of P-Index include consideration of transport factors such as soil erosion, soil runoff class, leaching potential, and distance from a water body along with management factors such as soil test P, P application method, and source and rate of P application. P-Index evaluation of these studies indicates that both agroforestry sites can be on a nitrogen-based nutrient management program. The relevance of some management practices such as application of manure vs. inorganic fertilizer is also discussed in light of the P-Index and the two agroforestry practices."

Summary of Key Findings

It is hypothesized that agroforestry systems may reduce the potential for nutrient loading of both surface and groundwaters in highly fertilized soils. Alley cropping and silvopasture are two major agroforestry practices in the southeastern United States. This chapter discusses the potential role of these two systems in addressing the problem of water quality in heavily fertilized/manured sandy soils.

The authors monitored the nutrient movement (N and P) through the soil profile under two agroforestry practices in different parts of Florida: a pecan (*Carya illinoensis*)–cotton (*Gossypium hirsutum*) alley cropping experiment at Jay, in the panhandle of Florida, and at a silvopasture experiment in the flatwood soils at Ona, central Florida.

The alley cropping system was set up in a pecan orchard on a Red Bay sandy loam. The soils at the site were very deep, well drained and moderately permeable with slow to medium runoff. Twelve plots were set up within the orchard, six of which were treated with inorganic fertilizer and the other six with organic (poultry manure) fertilizer. Poultry manure was added to plots at the same N rate as those receiving inorganic N fertilizer.

Preliminary results showed that NO₃-N concentration in the surface soils of the control plots (pecan tree plots with no fertilizer applications) were lower compared to both the fertilized nontrenched plots (F-NT) and the fertilized trenched plots (F-T), representing alley cropping and sole crop stands, respectively. Movement of NO₃-N through the soil profile followed the same trend as for surface soils, showing that more NO₃-N was taken up by the agroforestry system where there were interactions between the rooting systems of the pecan and cotton cropping systems. The NO₃-N concentrations in the soil profiles of F-T seem to have moved more through the soil profile to the 1-meter depth sampled compared to both the F-NT plots and the control plots.

The silvopasture experiment conducted on the flatwood soils at Ona, found that in addition to runoff losses of nutrients, leaching potential is high on the site. The soils were Spodosols soils, Ona fine sand. Ten soil profiles were sampled in the alleys of each of the silvopastoral site, an adjacent grazed pasture area and a nearby native flatwoods vegetation site.

The authors found that the silvopastoral system was more efficient in removing P from the soil profile than a regular pasture and thus might contribute significantly in reducing nonpoint source pollution.

The comparison of nutrient losses from an alley cropping site and from a silvopastoral site with monoculture systems under Florida conditions showed that these

agroforestry practices will likely reduce nutrient loss from a field when compared to monocultural practices. Thus, this report supports the hypothesis that agroforestry practices can reduce nutrient movement through soil profiles and potentially reduce nutrient loading in waterways. However, the authors emphasize that nutrient losses are highly site specific, and one of the most important components in the understanding of nutrient transport is the soil type. Therefore, definite conclusions can be arrived at only after obtaining additional experimental data from these and other agroforestry practices under different soil types and environmental conditions.

45. *Nair, V.D., and Harris, W.G. (2004). Soil Characteristics Affecting Phosphorus Storage Capacity Determinations. ASA/SSSA/CSSA Annual Meeting, October/November 2004, Seattle, WA. (CD Rom publication).*

Original abstract: "Soil test P as an environmental indicator of P loss from a farm has the shortcoming that low values do not confirm a significant capacity to retain P added as fertilizer or animal waste, and high values (such as in phosphatic soils) do not always suggest that the soil is a P source. Soil P storage capacity (SPSC), based on P saturation ratio (PSR), can be used to calculate the remaining reserve for P storage that captures risks arising from previous loading as well as inherently low P sorption capacity. The PSR rationale is that the ratio of extractable P to extractable Al and Fe can be used to estimate P in solution. Hence a PSR threshold can be established as an indicator of a safe P loading limit. The SPSC, calculated as (threshold PSR – PSR of the soil)*(extractable Al + Fe), provides a direct estimate of the amount of P a soil can sorb before exceeding a threshold soil equilibrium concentration. The threshold PSR used in the SPSC calculation is extractant-dependent, but the SPSC is independent of extractant provided that an accurate PSR threshold is determined for the extractant. Therefore the PSR calculated from routine soil test extraction data can be used for SPSC determination, which is a practical advantage for a risk assessment protocol. The relationship between PSR and WSP for a given extractant may shift depending on the range in Fe+Al values."

Summary of Key Findings

This presentation described phosphorus (P) storage capacity and sorption in soils using soil P storage capacity (SPSC), which is based on P saturation ration (PSR). An estimate of the amount of P a soil can sorb without exceeding a threshold, the SPSC, is calculated using the PSR. As a practical advantage for a risk assessment protocol, PSR calculated from soil test extraction data can be used to determine SPSC because SPSC is independent of the extractant.

46. *Nair, V.D., and Harris, W.G. (2004). A Capacity Factor as an Alternative to Soil Test Phosphorus in Phosphorus Risk Assessment. New Zealand Journal of Agricultural Research. 47:491-497.*

Original abstract: "Soil test phosphorus (P) concentrations (STP) are often used as measures of environmental P risk. However, a low STP is not valid justification for further P application because P sorption capacity may be low and P added could be lost to surface waters. The degree of P saturation (DPS) normalizes extractable P using extractable Al and Fe as a surrogate for P sorption capacity, but like STP, fails to convey a magnitude of capacity. We propose the use of a DPS-based prediction of the remaining soil P storage capacity (SPSC) that would capture risks arising from previous loading as well as inherently low P sorption capacity. The SPSC is a direct estimate of the amount of P a soil can sorb before exceeding a threshold soil equilibrium concentration. In this paper, we demonstrate the applicability of the SPSC for a variety of sandy soils impacted by dairy and poultry manure additions. The SPSC provides a means to assess the capacity of a soil to retain additional P and hence is a more useful indicator of P-related environmental risk than STP or DPS measures alone."

Summary of Key Findings

The soil test phosphorus (STP) or degree of phosphorus saturation (DPS) tests are currently used to assess the risk of phosphorus (P) leaching in soils. Both tests are used to determine the P sorption capacity of the soil and have been studied on dairy and poultry farms in the Middle Suwannee River basin. This paper suggests that the soil P storage capacity (SPSC) test, which determines the magnitude of the soil sorption capacity based on the STP and DPS methods, can provide valuable additional information not included in these tests. The SPSC determines the magnitude of the sorption capacity, which is important in evaluating the risk arising from low P sorption capacity. This information will allow a prediction of the life span of existing or proposed spray fields or improved pastures.

The SPSC uses the ammonium oxalate, Mehlich-1, or Mehlich-3 tests, which are used to determine DPS, to determine the P saturation ratio (PSR). This ratio is equivalent to DPS, however it does not contain the correction coefficient (found to be 0.5 for Middle Suwannee Sandy Soils) present in DPS. A DPS value of 30% has been found in previous studies to be a change-point, which values above the change-point have increased risk of P leaching. SPSC uses this value, converted to a PSR value of 0.15, to determine if a positive or negative sorption capacity exists, where a negative value indicates a P source and positive value indicates a P sink. The unit less ratio representing the remaining sorption capacity is multiplied by the soils actual soil capacity to determine the magnitude of sorption capacity. The SPSC calculation does not require additional laboratory testing that would not be required for the DPS calculation. Using the soils bulk density and thickness of the horizon the life span of soil with respect to further P sorption can be calculated.

Soil cores from two dairies and several poultry sites in the Middle Suwannee River basin were used to illustrate the SPSC test. Cores taken a minimally impacted spray

field (Dairy 1) showed relatively large amounts of remaining sorption capacity in all soil horizons. Core from heavily impacted spray field (Dairy 2) showed no capacity available and negative capacity in the top two soil horizons. Tests from a poultry site indicate that negative capacity existed in the top two horizons, but capacity exists in the lower horizons. For sites with negative capacity the hydrology of the area strongly affects the risk of soil leaching. For the poultry farm, near surface groundwater tables do not pose as great of a risk for leaching, if lateral subsurface flows or surface runoff does not occur, because capacity in lower layer can take up released P as the water table recedes.

The SPSC test can provide additional information on a soil's P leaching capacity that is not currently conveyed by the STP and DPS tests. Determining the magnitude of sorption capacity provides key answers in quantifying leaching potential or the life span of proposed BMPs.

47. Nair, V.D., Harris, W.G., and Graetz, D.A. (2004). *Predicting the Safe Phosphorus Storage Capacity of Sandy Soils*. Soil and Water Science Department, University of Florida. Research Brief. SWS 04-03. <http://soils.ifas.ufl.edu/departments/briefs/sws04-03.pdf>

Original abstract: Not applicable

Summary of Key Findings

Many dairies in the Suwannee River Basin (SRB) routinely apply phosphorous (P)-rich lagoon effluent onto spray fields despite the sandy soils insufficient ability to absorb the P. By relating extractable P to extractable Fe and Al, the finite capacity to retain P before increases in pore water concentrations can be seen. Research has indicated that a 0.15 molar ratio is a critical molar ration of P to Fe+Al, or P saturation ration (PSR). Using this critical value, research was extended to calculate the "safe P storage capacity (SPSC)" per unit volume of soil. This study used Mehlich 1, a standard soil test extraction method, in addition to SPSC to predict storage capacity for several locations in the SRB. Due to the variance of these results, consideration is being given to including SPSC as a more valid parameter than a soil test P, in the Florida P-Index for P risk assessment.

48. Nair, V.D., Portier, K.M., Graetz, D.A., and Walker, M.L. (2004). *An Environmental Threshold for Degree of Phosphorus Saturation in Sandy Soils*. J. Environ. Qual. 33:107-113.

Original abstract: "There is critical need for a practical indicator to assess the potential for phosphorus (P) movement from a given site to surface waters, either via surface runoff or subsurface drainage. The degree of phosphorus saturation (DPS), which

relates a measure of P already adsorbed by a soil to its P adsorption capacity, could be a good indicator of that soil's P release capability. Our primary objective was to find a suitable analytical protocol for determining DPS and to examine the possibility of defining a threshold DPS value for Florida's sandy soils. Four farmer-owned dairy spray fields were selected within the Suwannee River basin and soil profiles were randomly obtained from each site, as well as from adjacent unimpacted sites. The soil samples were divided either by horizon or depth, and DPS was determined for each soil sample using ammonium-oxalate (DPS_{Ox}), Mehlich-1 (DPS_{M1}), and Mehlich-3 (DPS_{M3}) extracts. All methods of DPS calculations were linearly related to one another ($r^2 > 0.94$). Relationships between water-soluble P and DPS indicate that the respective change points are: $DPS_{Ox} = 20\%$, $DPS_{M1} = 20\%$, and $DPS_{M3} = 16\%$. These relationships include samples from Ap, E, and Bt horizons, and various combinations thereof, suggesting that DPS values can be used as predictors of P loss from a soil irrespective of the depth of the soil within a profile. Taking into consideration the change points, confidence intervals, agronomic soil test values, and DPS values from other studies, we suggest replacing Mehlich-1 P values in the Florida P Index with the three DPS categories ($DPS_{M1} = <30, 30-60, \text{ and } >60\%$) to assign different P loss ratings in the P Index."

Summary of Key Findings

Monitoring of surface and subsurface soils for impairment for nutrients can play an important in a BMP program. This paper evaluates three soil tests to assess the degree of phosphorus saturation (DPS) in soils. Sandy soils on farmer-run dairies in the Middle Suwannee River basin were used to test DPS using the ammonium-oxalate, Mehlich-1, and Mehlich-3 extracts. The purpose of the study was to assess the relationship between ammonium-oxalate, which is difficult to measure and rarely performed in the United States, and two more common tests, Mehlich-1 and Mehlich-3. Using 57 soil profiles taken from four dairy sites and two unimpacted adjacent sites the degree of DPS was measured and related. The profiles were divided into surface and subsurface, where all subsurface profiles were averaged.

Results of the three tests on the surface and subsurface profiles showed a linear relationship between all three tests. A similar change-point was observed in all three tests, which preceded a rapid increases in water soluble phosphorus, is believed to indicate the point where negative water quality impacts from the soil may occur. Separating subsurface and surface soils did not significantly alter the change-point, indicating the methods are valid for any soil horizon.

Criteria to set environmental phosphorus limits using the Mehlich-1 P test, which is the most common in Florida, was developed by the authors. A threshold of 30% DPS was suggested to indicate possible impairment based on the change points, confidence intervals, and agronomic soil test values found in the study. A value of 60% DPS was considered a contributor to water quality impairment. The authors also suggested that

the Mehlich-1 P test and the DPS thresholds replace the current STP criteria in the Florida P Index.

The conclusions of this study indicate there are good methods to assess the potential for phosphorus impairment in surface and subsurface soils in the Middle Suwannee River basin. However due to the uncertainty presented in the calculation of DPS, a comprehensive scheme to assess potential P loss vulnerability, such as the P Index including DPS, should be considered and will provide a more robust indication of impairment.

49. *Nair, V.D., Harris, W.G., Ellis, L.R., and Hornsby, D.H. (2005). Issues in Phosphorus Movement in a Karst Basin. ASA/SSSA/CSSA Annual Meeting, November 2005, Salt Lake City, UT. (CD Rom publication)*

Original abstract: "The karst-dominated Lower Suwannee River Basin (LSRB) spans several Florida counties where agricultural activities have potential to affect the groundwater, springs, and estuary. Data show vertical movement of P in soils, but a common assumption is that P transport is restricted once it reaches limestone. This assumption need not be true since P-enriched water may not have sufficient contact time with the limestone to be retained by the rock. Previous research has indicated that there is a delay time between P loading from an agricultural source and the movement of the P to a water body. A concern is that once P reaches an outlet (e.g., spring), elevated P concentrations could persist for years even if P applications were discontinued. A GIS approach is being used to determine if there is a significant elevation of P in springs nearest to agricultural sources. Another issue for the LSRB is allocating the contributions of agricultural P and natural P from phosphatic geologic formations and soils upstream from the karst region of the Basin. Water quality data for river, tributaries, springs, and estuary reveal total P concentrations (mostly dissolved) of up to several mg L⁻¹ in tributaries of phosphatic watersheds. Do agricultural P inputs pose a significant ecological risk to the estuary in light of the natural P loading? This is a challenging question yet to be resolved."

Summary of Key Findings

This presentation examines the vertical movement of phosphorus and the effect limestone has on this movement. In addition, the effects of agricultural sources on natural springs and karst areas are discussed. This presentation concluded that further investigation is needed to determine if phosphorus from agricultural inputs is an ecological risk.

50. *Natural Resources Conservation Service (1994). Middle Suwannee River Hydrologic Unit Area Animal Waste Disposal Best Management Practices Demonstration Project. FDEP 319(h) Contract No. WM482; Final Report. Tallahassee, FL.*

Original abstract: "The Middle Suwannee River Area (MSRA) is located in North Central Florida in a region of karst topography and highly transmissive sandy soil. Due to the highly permeable soil and numerous sink holes, the aquifer is extremely susceptible to contamination by nonpoint source pollution. In addition there is substantial concern that poor quality groundwater contributed by numerous springs and seeps could degrade water quality of the Suwannee River. The river has been designated an Outstanding Florida Water (OFW) and is considered by many to be a river of outstanding national significance. Intensive agricultural activities including row crop production and animal husbandry operations associated with dairy and poultry production are the primary nonpoint source (NPS) pollutant categories that affect the basin. In the MSRA there are 46 dairy operations averaging 372 head each and 453 chicken houses averaging 15,000 chickens per house. Many of the waste management systems do not include provisions to provide adequate groundwater protection in karst terrain and some may not have sufficient land area on which to apply the waste at an acceptable agronomic rate. Applying waste nutrients at a rate greater than that, which can be, used by plants results in excessive leaching and degradation of water quality in the aquifer. The nitrate form of nitrogen is a particular concern since levels of 10 mg/l or higher in drinking water have been shown to constitute a health hazard to children and pregnant women.

Groundwater monitoring projects conducted in the basin by USGS prior to this demonstration project indicated that there are localized areas associated with dairy and poultry operations with concentrations of nitrate nitrogen in wells that exceed the 10 mg/ l. limit. Average nitrate concentrations in monitoring wells at seven dairies in Suwannee and Lafayette Counties were approximately 40 mg / l near unlined lagoons and 30 mg / l in the vicinity of high intensity areas and spray fields. Yet to be published data from wells among poultry houses at one of five locations contained 11 to 20 mg /l nitrate. Levels of 14 mg /l were reported in association with the "load out" field at another farm. The results of these on-farm ground water quality monitoring studies show a definite localized nitrate contamination in the watershed. A related study conducted by the Florida Department of Health and Rehabilitative Services indicates that nitrate concentrations are becoming a problem off-site from the source as well. Indications are that nitrate concentration in groundwater is increasing in the basin and that the rate of increase is accelerating.

The primary objective of this project was to demonstrate new and innovative technology in the treatment of animal waste. In association with the project two dairies and two poultry operations were selected to be used as demonstration farms. Design plans were prepared by the NRCS to retrofit the existing operations to introduce area dairy and poultry farmers to the best available technology and management practices for animal waste management, utilization and disposal. Specifically, for dairy operations the system includes lined lagoons, improved distribution systems for more even land application and distribution of lagoon effluent, and implementation of agronomic rate waste application and pasture

management concepts. The poultry operations were re designed to include covered concrete pads for dry litter storage and compost bins for bird disposal. The system provides for a safe method of bird disposal and containment for dry storage of litter until removed for sale or land application at appropriate agronomic rates. Composting facilities were completed and certified by NRCS at the James Wainwright poultry operation and at the Lindsey Jackson facility in April and June of 1993 respectively. A much-improved dairy waste management system was installed and certified complete by NRCS at the H & W Dairy in Suwannee County as of September 1994. After more than a year of planning and design efforts the second dairy operation elected not to participate in the program. While planning and designing the demonstration sites the NRCS has developed three computer programs to facilitate and standardize the process for future cooperators. These programs deal with evaluating poultry waste management systems, designing covered composting structures, and balancing water and nutrients on dairy farms. Also in completing the project the NRCS recognized that the long term success of a waste management system depends on the proper operation and maintenance of the facility by the landowner. Therefore much time and effort was spent in developing detailed operation and maintenance plans for each of the demonstration sites.

The two composting facilities were the first of their kind to be designed and built in Florida. Since their implementation the industry seems to have embraced the technology. Both the composting facilities and dairy waste management system have been featured in the annual waste management seminar."

Summary of Key Findings

This was a demonstration project that implemented state-of-the-art dairy and poultry waste management procedures designed to protect local drinking water wells from nitrate contamination due to leaching of nitrogen from animal waste sources. The project was conducted by the US Department of Agriculture, Soil Conservation Service (now the USDA Natural Resource Conservation Service) at the H&W Dairy and Wainwrights Poultry Farm in Suwannee County, Florida, to introduce area farmers to the best available technology, and animal waste management practices. To facilitate and standardize the planning and design process, the SCS developed three computer assisted procedures designed to aid in the: (i) balance of water and nutrients on dairy farms; (ii) evaluation of poultry waste management systems; and (iii) the design of composting structures. Specifically:

- a Lotus 1-2-3 spreadsheet template was developed to assist poultry waste management system planners determine the number of composting bins needed to handle bird deaths, and determine the amount of poultry litter storage area and number of acres on which to spread the stored poultry litter;
- a structural engineering computer program was developed to aid in the design of poultry composting facilities (i.e., structure size, stability, etc.); and

- a computer program was developed to forecast dairy manure and wastewater production quantities, to estimate stormwater runoff volumes from concentrated herd manure areas, and to aid in the preparation of a water budget and nutrient balance.

The computational procedures employed in these three programs comply with the standards and specifications of the Soil Conservation Service in determining waste storage and treatment facilities, and the number of land acres and crops required for the application of animal waste from confined feeding operations.

The evaluation of this demonstration project was conducted with the aid a computer model called "Ground Water Loading Effects of Agricultural Management Systems (GLEAMS), which was utilized to predict the leaching of nitrate-nitrogen into the ground water after implementation of the best management practices included in the demonstration project. Two scenarios were evaluated for dairy and poultry operations: (i) No-action; and (ii) Recommended alternative.

For the poultry operations evaluation, the no-action scenario was found to result in the leaching of approximately 380 pounds of nitrate-nitrogen per acre per year on an average basis. The recommended alternative consisted of a conservation plan that called for the spreading of poultry litter on a Bermuda grass hayfield overseeded with winter oats and harvested five (5) times per year. The conservation plan employed was found to prevent the leaching of 16,250 pounds per farm per year of nitrate-nitrogen into the Floridan Aquifer located below the study site.

For the dairy operations evaluation, the no-action scenario resulted in the leaching from pastures of approximately 7,500 pounds per farm per year of nitrate-nitrogen. The recommended alternative scenario consisted of reducing the cow herd density on pastures from 1.82 cows per acre to 1.4 cows per acre, and reducing the amount of time cows spent on pastures from 71 percent to 60 percent. Results of the recommended alternative evaluation indicated a reduction in nitrate-nitrogen leachate to 5,600 pounds per farm per year.

The total effect of this demonstration project (poultry and cow herd), was found to have prevented the leaching of 40,700 pounds nitrate-nitrogen into the Floridan Aquifer.

51. *Newton, G.L., Bernard, J.K., Hubbard, R.K., Allison, J.R., Lowrance, R.R., Gascho, G.J., Gates, R.N., and Vellidid, G. (2003). Managing Manure Nutrients Through Multi-crop Forage Production. J. Dairy Sci. 86:2243-2252. America Dairy Science Association.*

Original abstract: "Concentrated sources of dairy manure represent significant water pollution potential. The southern United States may be more vulnerable to water quality problems than some other regions because of climate, typical farm size, and cropping practices. Dairy manure can be an effective source of plant nutrients and large quantities of nutrients can be recycled through forage production, especially when multi-cropping systems are utilized. Linking forage production with manure utilization is an environmentally sound approach for addressing both of these problems. Review of two triple-crop systems revealed greater N and P recoveries for a corn-silage/Bermuda-grass/hay-rye haylage system, whereas forage yields and quality were greater for a corn silage-corn silage-rye haylage system, when manure was applied at rates to supply N. Nutrient uptake was lower than application during the autumn-winter period, and Bermuda grass utilized more of the remaining excess than a second crop of corn silage. Economic comparison of these systems suggests that the added value of the two corn silage crop system was not enough to off-set its increased production cost. Therefore, the system that included Bermuda grass demonstrated both environmental and economic advantages. Review of the N and P uptake and calculated crop value of various single, double, and triple crop forage systems indicated that the per hectare economic value as well as the N and P uptakes tended to follow DM yields, and grasses tended to out-perform broadleaf forages. Taken across all systems, systems that included Bermuda grass tended to have some of the highest economic values and uptakes of N and P. Manure applied at rates to supply N results in application of excess P, and production will not supply adequate quantities of forage to meet the herd's needs. Systems that lower manure application and supply supplemental N to produce all necessary forage under manure application will likely be less economically attractive due to additional costs of moving manure further and applying it to greater land areas, but will be environmentally necessary in most cases. Intensive forage systems can produce acceptable to high quality forage, protect the environment, and be economically attractive. The optimal manure-forage system will depend on the farm characteristics and specific local conditions. Buffers and nutrient sinks can protect streams and water bodies from migrating nutrients and should be included as a part of crop production systems."

Summary of Key Findings

Dairy manure has significant potential to cause water pollution, especially when large numbers of cattle are maintained on limited land areas. Any manure utilization scheme or plan that does not recognize the need to deal with nutrients leaving the field or production area is incomplete. Nitrogen and P are the nutrients of primary concern, and preventing their movement to surface waters or groundwater should be a primary objective of manure management. Published data suggests that the southern US may be more vulnerable to water pollution from manure than other regions of the country, partially due to lower plant nutrient uptake per hectare. The author presents options to increase nutrient uptake from fields where manure is applied and concludes that landscape features, such as vegetated filter strips and

riparian forests, can potentially be coupled with production systems to reduce the environmental risks of escaped nutrients.

Dairy operations that integrate crop and animal production can utilize manure as a plant nutrient source to reduce expenditure on both fertilizer and manure disposal. Multi-crop systems with year-round forage production will help meet the objective of linking increased nutrient uptake with economical production of quality forage. For the two triple-crop systems reviewed, N and P recoveries were greater for the corn silage-Bermuda grass hay-rye halyage (CBR) system, while yields and forage quality were greater for the corn silage-corn silage-rye haylage (CCR) system when manure was applied at rates to supply N. Bermuda grass is apparently capable of retrieving more of the remaining nutrients applied during the lower-uptake, autumn-winter period than a second crop of corn silage. Examination of several single, double and triple crop systems suggest that the per hectare economic value of the forage produced as well as the N and P uptakes tend to follow DM yields. Over time, irrigated forages produce higher value forage and recycle more nutrients than dry land production, and systems which include Bermuda grass tend to have some of the higher economic values and recoveries of N and P.

A budget analysis of the two triple-crop systems indicated total annual revenue was 13 to 32 percent higher with manure than with fertilizer. Similarly, net returns to land and management were higher in both cropping systems with manure than with fertilizer application. However, the management practices as implemented were proven to be economically profitable but environmentally unsustainable due to P runoff.

Forage systems that produce the highest yields and/or forage quality do not necessarily have the greatest economic advantage, as production costs may negate these advantages. Applying manure based on N normally results in excess application of P, and inadequate forage production to meet the herd's forage needs. Applying manure to the land area needed to produce enough forage for the herd, then supplementing with N, will improve the P balance, but additional measures may be needed.

The riparian buffer, partly surrounding the project area, was a very effective nutrient sink for the N and P coming from the forage production system located upslope. In fact, the authors demonstrated that riparian buffers can produce a fivefold reduction in nitrate concentration and a threefold reduction in P concentration in water moving from manured fields to streams or lakes. Additionally, trees and vegetation serve to stabilize stream banks, thus reducing erosion during high flow periods.

Appropriately located trees can also reduce odors and nutrients in air down-wind of livestock facilities and manure application fields. Direct economic benefits from trees occur only on the longer term, but properly managed tree harvest from buffers and riparian areas can be accomplished without destroying their water protecting

function. Thus, riparian buffers and vegetation should be a component of manure utilization systems, especially in humid regions.

52. *North Florida Research and Education Center – Suwannee Valley (2002). Field testing of Possible BMPs for Watermelon.*

Original abstract: “spring watermelons were grown between 1998 and 2002 following current IFAS fertilization and irrigation recommendations (Maynard and Olson, 2001). Nitrate levels in the soil water at the 1.6-m and 7-m depth were monitored every three weeks with suction-cup lysimeters and wells. Watermelon marketable yield ranged between 43,680 and 72,280 kg/ha, which was comparable to current commercial yields (Witzig and Pugh, 2001). Nitrate-nitrogen concentration in the lysimeters ranged from 20 to 150 mg/L NO₃-N except when cover crops were grown between vegetable crops. Under cover crops, nitrate concentration in the lysimeter samples ranged between 5 and 20 mg/L NO₃-N. Nitrate concentration in the monitoring well samples was always below 20 mg/L NO₃-N. It was concluded that economical yields of watermelon may be produced with current fertilizer and irrigation recommendations. However, it was not possible to maintain NO₃-N levels in the soil water or the shallow groundwater below the EPA drinking water standard, when current production recommendations were followed. The relevance of using the EPA drinking water standard (10 mg/L NO₃-N; USEPA, 1994) as the threshold for discharge monitoring has been questioned because the fate of nitrate below the root zone is unknown, and water just below the root zone of vegetables is typically not used for potable water supply. Monitoring water below the root zone does account for dilution of nitrate in the root zone. However, this concentration has been selected because no alternative threshold exists for shallow water. Because NO₃-N moves with the water front, optimizing irrigation management may reduce nitrate leaching.”

Summary of Key Findings

Report not found.

53. *Ramnarine, R. (2003). Predicting Phosphate Soil distribution in Alachua County, Florida. M.S. Thesis. Soil and Water Science Department, University of Florida.*

Original abstract: “Phosphatic soils occur extensively in Florida, where phosphatic geologic materials are exposed by erosion. It is important to identify areas of phosphatic soil because they influence phosphorus risk and environmental impact assessments. Using phosphatic geology as the sole criterion for determining phosphatic soil distribution is insufficient, since deposits may be mapped at depths that do not influence soil properties. We tested a geographic information systems (GIS) approach to predicting the distribution of phosphatic soils in Alachua County, Florida, based on landscape/geologic/soil conceptual model that takes into account

features associated with dissection and erosion. The hypothesis was that phosphatic soils occur on erosional landscapes where phosphatic geologic materials are exposed or are near the surface.

“Two areas (scarp and plateau) were delineated based on an initial prediction that these would have the highest and lowest probability of phosphatic soils, respectively. Soil map units were designated as ‘obligate’ if they occurred at 90% or greater area in the scarp compared to the total area (scarp and plateau); and ‘facultative’ if their occurrence on the scarp was between 60 and 90%. An initial predictive phosphatic soils map was produced by including all ‘obligate’ map units and only ‘facultative’ map units sharing a boundary with an ‘obligate’. Phosphatic soils on the plain and scarp regions were distinguished because of suspicion (from geologic information) that the plain would have a lower proportion of phosphatic soils than the scarp. Soils predicted to be nonphosphatic made up the ‘nonphosphatic’ region.

“Fifteen sample sites for field validation were randomly selected within the scarp, plain, and nonphosphatic regions. Samples were taken at two depths for each site: upper (0 to 25 cm) and lower (100 to 125 cm). Total phosphorus (TP) and nodule mineralogy were determined. Mean TP concentration for the lower depth was 6195 mg kg⁻¹ for the scarp phosphatic region, 2485 mg kg⁻¹ for the plain phosphatic region, and 193 mg kg⁻¹ for the nonphosphatic region ($p < 0.0001$). The aluminum phosphate mineral, wavellite, was found in nodules of samples with TP concentrations of 902 mg kg⁻¹ or higher. Based on the latter and corroborative TP data for the three regions, a phosphatic soil was operationally defined as one containing ≥ 1000 mg kg⁻¹ TP at the 100 to 125 cm depth, with higher TP concentrations at the lower sampling depth. The initial predictive map was revised to show that the probability of finding a phosphatic soil was highest for the scarp phosphatic region (73%), medium for the plain phosphatic region (33%), and low for the nonphosphatic region (7%) ($p < 0.001$). The final map corresponded reasonably well with a radon protection map, but some discrepancies suggest that radon could still be a risk even when the source is below the 2-m soil zone.”

Summary of Key Findings

Phosphatic soils are prevalent in Florida and because they influence phosphorus risk and environmental impact assessments it is important to identify areas where they occur since they do not necessarily correspond to phosphatic formations on a geological map. This study used soils information, geologic, and topographic information to develop a predictive phosphatic soil map in Alachua County, Florida using a geographic information systems approach. An initial predictive phosphatic soils map was produced illustrating “obligate” areas, which are areas with more than 90% of the total area initially predicted to have the highest probability of phosphatic soils, and “facultative” areas, areas with 60% to 90% of the total area initially predicted

to have the highest probability of phosphatic soils, that share a boundary with an "obligate" area. The "nonphosphatic" regions were comprised of those areas predicted to be nonphosphatic. Soil samples were taken at two depths from fifteen different sites and total phosphorus (TP) and nodule mineralogy were determined for each sample.

Sample analysis indicated an increase in TP concentration with depth for all phosphatic soils sampled and comparable TP concentrations through the depth of samples for most nonphosphatic soils sampled. These results illustrate how phosphatic soil occurrences can not be determined from geologic maps alone. The final map was compared to a radon protection map and they correspond reasonably well, but based on some disparities and a soil depth of only 2-meters used for assessment, radon risks could be possible where radon sources are below 2-meter depth.

54. *Ramnarine, R., Harris, W.G, Nair, V.D., and Portier, K.M. (2003). Prediction of Phosphatic Soil Distribution in Alachua County, FL. Southern Branch ASA Annual Meeting, Feb. 1-4, 2003. Mobile, Alabama. Abstracts p11.*

Original abstract: "Phosphatic soils occur extensively in Florida, where phosphatic geologic materials are exposed by erosion. It is important to identify areas of phosphatic soil because they influence phosphorus risk and environmental impact assessments. Using phosphatic geology as the sole criteria for determining phosphatic soil distribution is insufficient since deposits may be mapped at depths which do not influence soil properties. This study is testing an approach to predicting the distribution of phosphatic soils in Alachua County, FL, based on a landscape/geologic/soil conceptual model which takes into account features associated with dissection and erosion. The hypotheses are that (i) phosphatic soils occur where phosphatic geologic formations are exposed at the surface and (ii) these soils will have distinguishing properties captured by the map unit. The model is being applied using Geographic Information Systems (GIS) software to inter-relate topographic features and geologic information. Two areas were chosen for study, one predicted to contain phosphatic soils and another where the soils are most likely not phosphatic. Soil map units will be identified in each delineated area and determined to be 'obligate' or 'facultative' depending on their percentage occurrence within the area initially designated as having the highest probability of being phosphatic. Maps are being developed identifying phosphatic soil map units based on the model. The final map will be validated by field testing (sampling) and laboratory analyses of soil samples (mineralogy, total phosphorus). The expected outputs include a list of phosphatic soil map units and a map showing areas with a high probability of phosphatic soil occurrence."

Summary of Key Findings

This study focuses on the use of a conceptual model and accounting for features associated with dissection and erosion to predict the distribution of phosphatic soils. Phosphatic soil map units will be identified and mapped based on the model simulations. Field testing and laboratory analysis of soils will be conducted to validate the final phosphatic soil maps.

55. *Reck, W.R., Campbell, K.L. (ed.), Graham, W.D. (ed.), Bottcher, A.B. (1994). GLEAMS Modeling of BMPs to Reduce Nitrate leaching in Middle Suwannee River Area. Environmentally sound agriculture: Proc. of the second conference, Orlando, Florida, USA, 20-22 April 1994. pp. 361-367; ASAE publication 04-94, St Joseph, MI.*

Original abstract: “The effectiveness of conservation practices to reduce NO₃ leaching to the Floridian Aquifer (USA) through improved agricultural waste management systems was estimated. Groundwater monitoring of the Middle Suwannee River Area (MSRA) showed high concentrations of NO₃-N near (down gradient from) intensive agricultural operations. Dairy and poultry farms have high NO₃ levels below these operations compared to nearby control wells. During the summer of 1992, interviews were conducted with 8 dairy farmers and 16 poultry farmers in the MSRA. The data from the interviews was used to develop 'typical' values to input into the computer model Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) in order to predict N leaching under various management schemes. Several alternative management scenarios were modeled to determine the most effective method of reducing the leaching of NO₃-N. These best management practices (BMPs) included determination of optimal loading rates for poultry litter, efficient crop rotations, number of harvests for hay land crops, irrigation of agricultural crops with lagoon effluent, reduction of commercial fertilizer used, and control of HIA. This information was used to estimate an average reduction in NO₃ leaching of 77% for participating poultry farms and 55% reduction in NO₃ leaching for participating dairy farms with the use of BMPs. The overall effectiveness of implementing BMPs for the MSRA was estimated to be a 50% reduction in NO₃-N leached for all dairy and poultry farms combined.”

Summary of Key Findings

The research in question used the GLEAMS computer model to provide a recommended alternative practices for dairy and poultry farming in Middle Suwannee River Basin (Suwannee County and Lafayette County, Florida). The typical poultry farming practices were determined through a series of interviews conducted by the United States Soil Conservation Service (SCS) in the summer of 1992. These practices and measured nutrient concentration from poultry litter were used to develop a nutrient balance in the GLEAMS model. Similarly, interviews of dairy farmers with the SCS and Florida Institute of Food and Agricultural Sciences (IFAS) were used to develop the typical dairy farming operation. This data was used to develop a dairy farm GLEAMS model.

The GLEAMS models were used to assess several alternative practices for both poultry and dairy farms. Alternative practices focused on application of litter or manure, crop rotations, fertilization, and several other management practices. A set of alternative management practices was developed from the GLEAM modeling results for both poultry and dairy farms.

The application of the select alternative poultry farming techniques was able to reduce the nitrate leaching by 77 percent. To achieve this reduction the following alternative practices were implemented in the model:

- Reduction of liter application per hectare from 23.7 to 22 tons per hectare per year,
- Increasing harvests from 1 to 5 per year, and
- Over seeding hayfields with winter oats.

Dairy farming uses a relatively complex management practices. Sets of alternative management practices were developed from the GLEAMS model that reduced nitrate leaching from the dairy by 56%. The alternative practices included:

- Reducing the pasture density of cattle, from 4.5 to 3.5 cows per hectare,
- Decreasing the time each cow spends on pastures from 71% to 67%,
- Collect wastes to be conveyed to the a storage pond from both the High Intensity Area and Milking/Feeding area,
- Increasing harvests from 1 to 5 per year, and
- Over seeding hayfields with winter oats.

The results of this study indicate that large reduction in nitrate leaching is possible in Middle Suwannee River basin dairies and poultry farms. Alternative practices in pasture crop selection, increased harvesting, and the reduction of untreated wastes appear to be key ways to reduce nitrate leaching.

56. *Rhue, R.D., Harris, W.G., and V.D. Nair, V.D. (2003). Long-term Phosphate Sorption/Desorption in Sandy Soil. ASA/SSSA/CSSA Annual Meeting, November 2-6, 2003. Denver, CO. CD Rom publication.*

Original abstract: "Column studies were initiated to study long-term P retention in sandy soils taken from the Suwannee River Basin of Florida and Georgia. Soil was placed in columns and solution was passed through the columns under water-unsaturated conditions at low pore water velocities. Two or more cycles consisting of a P solution followed by P-free solution were conducted over periods of 18 to 24 months. Due to the long time periods and low pore water velocities, sorbed P and P in solution reached an apparent equilibrium. A P leaching model was developed based on the following assumptions: P sorption/desorption was reversible but hysteretic, sorption/desorption kinetics were negligible, and a single set of Freundlich

parameters were sufficient to describe multiple sorption/desorption cycles. The column is modeled as discrete segments and P leaching consists of the displacement of the pore water in each segment by that from the overlying segment, followed by partitioning of P between solid and solution phases. The P concentration in the input solution can be changed to simulate cycles of P application, allowing both adsorption and desorption to occur simultaneously in various segments within the column. The model was able to simulate several important retention characteristics in these columns. The model will be expanded to simulate P leaching in profiles and the simulations compared to actual P leaching at several field sites."

Summary of Key Findings

This research used column studies of sandy soil to determine long-term phosphorus (P) retention and a P leaching model was developed. Results of the research and model simulations indicated that important retention characteristics were simulated by the model. Future research will expand the model to simulate P leaching in profiles and compare these results to actual leaching in the field.

57. Rhue, R.D., Nair, V.D., and Harris, W.G. (2003). *The Role of Amorphous Iron and Aluminum in Phosphorus Retention in Sandy Soils of the Suwannee River Basin. Soil and Water Science Department, University of Florida. Research Brief. SWS 03-04.* <http://soils.ifas.ufl.edu/departments/briefs/sws03-04.pdf>

Original abstract: Not applicable.

Summary of Key Findings

In order to maintain water quality, the soil's ability to retain phosphorus (P) against leaching is critical. The most important soil components affecting this leaching are the amorphous oxides of iron and aluminum, which an ammonium oxalate extraction procedure can quantify. This project utilizes numeric analysis to derive data that can be used in leaching models. Plotting a standard soil test, Mehlich- 1 P, versus oxalate extractable P, results indicated that oxalate extractable P largely makes up P bound by amorphous iron and aluminum oxides in acidic soils in the Suwannee River Basin. This study also demonstrated the use of adsorption isotherms to measure P retention in soil. A plot of the amount of P adsorbed by the soil versus the amount of P in solution shows that for sandy soils that range in amorphous iron and aluminum content, P adsorption increases as iron and aluminum increase. The third analysis in this study was a comparison of the percent relative P adsorption (RPA) versus the oxalate extractable iron and aluminum for soil samples with an RPA <70%. This analysis indicated that P retention capacity decreases as P loading increases.

58. Rhue, R.D. , Nair, V.D., and Harris., W.G. (2003). *P Quick Test. Soil and Water Science Department, University of Florida. Research Brief. SWS 03-03.* <http://soils.ifas.ufl.edu/departments/briefs/sws03-03.pdf>

Original abstract: Not applicable.

Summary of Key Findings

In order to predict phosphorus (P) retention capacity in soil, the depth of elevated P concentration is needed. Research has found that the depth to background P levels can be found using a field test, known as the '*P quick test*', which relates to the water soluble P (WSP), Mehlich-1 soil test P and the degree of P saturation laboratory tests. So far soils from two poultry operations and two dairy spray fields were used to test the '*P quick test*.' Data collected from these experiments suggests when predicting depth to background P concentrations, the '*P quick test*' will be reliable and practical.

59. Rhue, R.D., Harris, W.G., and Nair, V.D. (2003). *A Model for Longterm P Leaching in Sandy Soil. Soil and Water Science Department, University of Florida. Research Brief. SWS 03-02. <http://soils.ifas.ufl.edu/departments/briefs/sws03-02.pdf>*

Original abstract: Not applicable.

Summary of Key Findings

In order to effectively utilize land for waste disposal while still protecting water quality, an accurate estimate of P retention capacity is required; however, this can be difficult because adsorption and desorption of P are slow reactions taking months or years to reach equilibrium. A clear understanding of this behavior is needed to accurately predict P loading capacity; therefore, a model has been developed to help explain the P leaching. Although this study does not provide actual data, additional P leaching research on sandy soils should validate the model and indicate its accuracy. Nevertheless, the examples provided in this study proved that the model qualitatively shows the effect on P leaching from soil properties and management practices.

60. Rhue, R.D., Nair, V.D., and Harris, W.G. (2005). *A Quick Field Test for Evaluating Phosphorus Mobility in Sandy Soils. New Zealand Journal of Agricultural Research. New Zealand J. Agric. Res. 48:367-375.*

Original abstract: "Assessing the risk of phosphorus (P) leaching in sandy soils requires a valid and practical indicator of the depth to which applied P has moved in soil. This paper describes a rapid field test for soil P called the Phosphorus Quick Test (PQT) that is based on the phosphomolybdate blue procedure. One gram samples of soil taken from known depths within a soil profile were saturated with 0.10 M HCl on a porcelain spot plate and a few drops of the solution were treated with phosphomolybdate reagent to form a blue color. The depth to which P has moved into the soil can be determined visually after only a few minutes. A comparison of the PQT results with soil (Mehlich-1 P) and water-soluble P tests showed that the PQT could accurately determine the depth of P movement in sandy soils. Results of the PQT at a

field site that had received a single, heavy application of dairy lagoon effluent showed that considerable downward movement of P occurred in some areas of the field as a result of the effluent application.”

Summary of Key Findings

This paper documents the Phosphorus Quick Test (PQT), which was developed to quickly evaluate soil phosphorus (P) concentration in the field setting. The study compares the PQT to the Mehlich-1 P (M-1 P), and water-soluble P (WSP) tests that have been previously shown to provide good indication of the phosphorus leaching in the Middle Suwannee River basin.

The PQT uses the phosphomolybdate blue procedure developed by Murphy and Riley (1962). Approximately 1 gram of soil is placed in a porcelain spot plate and saturated with 0.1 M HCL. The saturated soil is allowed to stand for 5 minutes. The liquid from the sample is transferred to an adjacent well, where the color reagent is added. A blue color will develop in the liquid within several minutes and reaches maximum intensity in 10 to 15 minutes. A more intense blue color indicates higher soil P.

The PQT was compared using 32 cores from a dairy and poultry farm in the Middle Suwannee River basin. A single large application of lagoon effluent was sprayed onto existing hayfields, which had not been used previously as spray fields. Soil samples were taken after one year and compared using the PST, M-1 P, and WSP tests. The results of the tests showed good agreement between PQT, M-1 P, and WSP tests. The results of the test indicate the blue color in the PQT test was detectable at water-soluble P concentrations greater than 0.6 to 0.9 mg per kg. Additionally, results indicate the optimum concentration range for the PQT is between 1 and 15 mg P per liter. The application of PQT was successful; however drying of the solution can an issue on hot days.

Results of the soil cores on the dairy and poultry site showed substantial variation in P concentration in the soil profile. Seven of the 32 samples were unusable, as the applied P had moved below one meter in one year's time. These findings reinforce the benefit of quickly determining soil P concentrations to be used as in onsite-screening to determine if a soils core warrants laboratory testing or if additional coring is necessary. Additionally, the PQT could be reference to Mehlich-1 P and used as a surrogate in the Florida P index to quickly determine which soils may be contributing to P leaching. For these reasons, incorporating the PQT or other similar tests can provide significant benefit to a BMP monitoring program.

61. *Rhue, R.D., Harris, W.G., and Nair, V.D. (2006). A Retardation-based Model for Phosphorus Transport in Sandy Soil. Soil Science. 171:293-304.*

Original abstract: "Animal-based agricultural is practiced in many areas of the world on sandy soils in which leaching is the major transport process for phosphorus (P). Disposing of large quantities of animal wastes on these soils can overload their P retention capacity and lead to elevated concentrations of P in ground and surface water. Subsurface zones may represent sizeable reserves for storing P, but to effectively utilize these zones, a way of predicting how much P will be adsorbed before solution P concentrations exceed acceptable limits must be known. This article describes a simple transport model that simulates P leaching through soil that uses soil bulk density, volumetric water content, solution P concentration, and column length as inputs. Phosphorus is partitioned between soil and solution phases using Freundlich equations whose parameters are calculated from a single-point adsorption measurement. The model was used to simulate P leaching from 40 columns containing samples of A, E, or Bt horizons of soil from the Suwannee River basin of Florida and Georgia, in the United States; some of which had been loaded with P from dairy and poultry manure applications. The degree of P saturation, DPS, based on acid ammonium oxalate-extractable P, Fe, and Al, ranged from 4% to 140% for these soils. No soil with a DPS of <50% had an initial column leachate P concentration that exceeded 0.10 mg L⁻¹.

The relationship between measured and simulated retardation of P for soils with a DPS of <50% was good ($R^2 = 0.873$), but the measured retardation exceeded simulated retardation by about 30%. This was attributed to the fact that the Freundlich parameters were based on a 24-h equilibration between soil and solution, whereas the column studies covered a period of about 2.5 years. The relationship for soils with a DPS of >50% was not as good ($R^2 = 0.333$) but could be improved considerably ($R^2 = 0.661$) by setting the initially adsorbed P in the model equal to the oxalate-extractable P and adjusting the desorption exponent in the Freundlich equation to allow for greater desorption of P. The model was able to capture several important aspects of P retention in sandy soil despite its simplicity and small number of inputs."

Summary of Key Findings

This research studied a model's effectiveness in simulating phosphorus (P) transport. In terms of protecting water quality, it is essential to predict the rate of P movement through soil. In sandy soils, the rate of downward movement of P depends on its retardation, which is controlled by adsorption/desorption (A/D) reactions. Due to poor understanding of these reactions, empirical models that employ multiple sites and multiple reactions are generally used when simulating this A/D behavior. After various model studies, this research concluded that although these models simulate P transport well, there is a need to optimize the rate coefficients for each soil and each set of conditions, which limits their use. This research used soil profiles from two dairy and two poultry operations within the Suwannee River basin to study the focus model. Ten samples from each of the four sites (40 total samples) were used in long-term studies comparing the model simulation results with measured values. Based on

this research, the short-term P sorption measurements are expected to underestimate the long-term sorption behavior and model research results resulted in higher measured retardation than found in model simulation. Despite this difference, research found that for soils with a degree of P saturation (DPS) <50%, the measured retardation consistently exceeded the simulated retardation by approximately 30%. Initially, soils with a DPS of >50% had a high percent difference, but research found this could be improved to the same trend as low-DPS soils by additional inputs and adjusting the soil parameters to account for previously adsorbed P and greater desorption of P at high loadings, respectively. This research also found no ability to retain P that was applied to columns with a DPS > 50%. This study only used uniform soil columns, but research concluded that this model should also be useful in simulating P transport through layered soil columns; furthermore, the model should then be useful in protecting ground and surface water from P enrichment through its use of predicting P loading capacities of whole soil profiles.

62. Sanchez, J.F. (2004). *Water and Nitrate Movement in Poultry Litter Amended Soils. PhD Dissertation, University of Florida, Gainesville, FL.*

Original abstract: "Nitrate leaching from land application of animal wastes has been linked to increasing levels of nitrate in drinking water in the Suwannee River basin over the past several years. The main focus of this research study was to describe nitrate movement in soils under long term poultry litter management. Pedo Transfer Functions (PTF) were developed to describe the water retention characteristics that are valued as low resource alternatives. The PTFs were found to be influenced by the clay content followed by the soil organic carbon content. Mineralization of poultry manure was determined in the laboratory columns during a 60-day incubation period. At the end of the 60-day period, 69, 51, 58, 47, 48, 43, and 39% of the total nitrogen applied was mineralized for applications equivalent to 3, 6, 9, 12, 15, 18 and 21 Mg ha⁻¹ of poultry manure respectively. LEACHM is a potential modeling tool for characterizing nitrate and water movement in soils. A statistical procedure termed the Scenarios Technique was effectively combined with LEACHM to provide a predictive approach for nitrate losses from the drainage zone for various nutrient management levels. Higher N rates produced higher cumulative nitrate values in the soils. An application of additional 50 kg ha⁻¹ in the form of ammonium nitrate along with the standard litter application resulted in higher nitrate levels in the drainage indicating that the source of N was a critical factor when making nutrient management decisions. The scenarios established with a sequence of wet dry years had a strong effect on the nitrate leaching suggesting that the effect of adverse weather conditions on the nitrate leaching risk could be forecast with the help of the Scenarios Technique. The effect of textural changes in the soil profile on soil nitrate movement was less pronounced compared to the total rainfall received. The Scenarios Technique was found to be a reliable tool for evaluation of best nutrient management practices in Utilisols."

Summary of Key Findings

The application of poultry litter was associated with the accumulation of nitrate in the surface soil layers from previous management. If the weather conditions favored a strong growth of bahia grass then no new peaks in nitrate concentrations were identified in the clay layer. Isolated soil nitrate peaks not directly related with applications of litter could not be completely explained although partly could have been due to differential rates mineralization of residual organic N from the poultry litter. Rainfall played a primary role in the movement of nitrate through the soil profile.

The continuous application of poultry litter resulted in lower bulk densities at the top soil layers in spite of the higher sand content at those depths in the three profiles. The saturated hydraulic conductivity was higher in the soil surface layers and decreased with depth as clay content increased with depth. Surface soil layers being sandy lost water rapidly even at the smallest increase in extraction pressure.

Campbell's model is better than PTFs in the estimation of water retention characteristics. At least in the dataset used, where the intrinsic variability was due to the changes in the soil profile, Campbell's was able to predict water content at all depths. PTFs however remain an alternate option to describe soil water movement especially when the resources are limited. PTFs with a wider range of application should be developed to estimate water retention characteristics on areas where the information is not available.

At 60 days, net N mineralized was 42.1, 63.2, 106.4, 115.3, 146.7, 159.4 and 167 mg kg⁻¹ for equivalent land applications of 3, 6, 9, 12, 15, 18 and 21 Mg ha⁻¹ of poultry manure representing 69, 51, 58, 47, 48, 43 and 39 % of the total N applied. Our results suggested that new Best Management Practices should not only recommend a decrease in the total number of poultry litter applications but also the partitioning of that amount into smaller doses.

The four soil points evaluated demonstrated the magnitude of variability even in a small area (11 ha.) that was subjected to a relatively homogenous management. The inherent spatial variability observed proved that generalization about the potential pollutant risk related with agricultural practices from an area was not possible. Such limitations should be duly considered when formulating best management practices.

LEACHM is a potential tool for the analysis of BMP scenarios in Ultisols of North Florida. The differential sensibility of the model to different variables of the environment should be considered when applying the model. The model responded well to normal doses of nitrogen below 250 kg/ha/year of N from the poultry litter. However the performance of the model when massive doses of nitrogen are applied to the soil was not satisfactory.

The scenarios technique was able to differentiate between different N options developed by IFAS for Bahia grass fertilization, characterizing the nitrate movement in the profile and calculating the expected nitrate load in the drainage. Higher N application rates obviously resulted in higher cumulative nitrate values in the drainage.

The application of additional nitrogen from ammonium nitrate with the application of poultry litter as the main source of nitrogen was a potential source for leaching in Ultisols of North Florida. The scenarios established with a sequence of wet dry years suggested that the effect of adverse weather conditions on the nitrate leaching risk could be forecast with the help of the scenarios technique.

63. *Simonne, E.H., Studsill, D., Hochmuth B., Olczyk, T., Dukes, M.D., Munoz-Carpena, R., and Li, Y. (2003). Drip Irrigation: The BMP Era - An Integrated Approach to Water and Fertilizer Management for Vegetables Grown with Plasticulture. Document HS917. Florida Cooperative Extension Service, Institute of Food and Agricultural Science, University of Florida, Gainesville.*

Original abstract: "In Florida, plasticulture is currently used on approximately 60,000 acres of vegetable (mainly tomato, bell pepper, eggplant, strawberry and watermelon). The Florida drip irrigation school is a one-day educational program offered by the Institute of Food and Agricultural Sciences at the University of Florida focusing on drip irrigation. Through talks, hands-on demonstrations and discussions, the goal of this program is to teach and help vegetable growers better manage fertilizer, water and fumigant applications through drip systems and to prepare them for the BMP era. This program involves county and state-wide Extension faculty and researchers, and members of the irrigation and fertilization industries. This article presents a summary of the information discussed on fertilizer management, irrigation scheduling, and drip system maintenance and troubleshooting. A list of additional references is also included."

Summary of Key Findings

This paper presents a summary of the several sections of the Florida Drip Irrigation School presented by the University of Florida Institute for Food and Agricultural Sciences. Information on fertilizer management, irrigation scheduling, and drip system maintenance and troubleshooting are discussed. The paper focuses on key principles of fertilizer management and irrigation scheduling on vegetable plasticulture, which is the use of plastic in horticulture such as drip irrigation lines or plastic mulch. The key principles were developed by the authors under the assumption that the farmer will need to reduce environmental impacts due to Total Maximum Daily Load (TMDL) in nearby water body. Principles were divided into fertilization and irrigations groupings.

Specific fertilizations recommendations have been developed by University of Florida Institute for Food and Agricultural Sciences on the type, quantity, and timing necessary for specific vegetable production. The principles presented in the document were developed for use with these recommendations and are presented below.

1. With plasticulture, think in terms of rows Y and not in terms of field surface for irrigation and fertilization.
2. Plants need all the essential nutrients.
3. Soil test and follow the recommendation.
4. Monitor crop nutritional status and discover how healthy the vegetable plants are.

Irrigation scheduling focuses on the quantity and timing of irrigation. It requires the target water volume to be known, guidelines on how and when to split irrigation and rainfall and soil moisture to be taken into account. The authors' principles of irrigation are presented below.

1. Irrigation amount must reflect crop water use, no more, no less
2. Irrigation amount should not exceed soil water holding capacity. Otherwise, water is wasted and mobile nutrients are leached.
3. Rainfall contributes little to replenish soil moisture because of the plastic mulch.
4. Monitor soil moisture level daily to discover how much water stress the crop is exposed to.
5. Keep irrigation records daily.

Simonne et al. have developed nine recommendations or BMPs to apply drip irrigation and plasticulture for vegetable production. These recommendations aim at distributing the proper fertilization and irrigation scheduling to reduce the nutrient loads to the environment, while maintaining economic yields.

64. *Simonne, E.H, and Hochmuth, G.J. (2003). Principles of Fertilization and Irrigation Management for Vegetables Crops grown in Florida in the BMP Era: Introduction. Document HS897. Florida Cooperative Extension Service, Institute of Food and Agricultural Science, University of Florida, Gainesville.*

Original abstract: Not applicable.

Summary of Key Findings

Adequate management of fertilization and irrigation has always been recognized as one of the keys to successful vegetable production in Florida. Thus, fertilization and irrigation practices have aimed at supplying enough nutrients and water to ensure

economical yields. As the combined cost of fertilizer and water has traditionally represented approximately only one third of the pre-harvest production costs, fertilizer and water application rates above recommended rates have been considered as an "inexpensive" insurance for high-yielding crops. With the increase in environmental awareness, fertilizer costs, and competition among water users, the need for higher levels of vegetable crop management has emerged. As water is involved in nitrate and phosphate movement out of the root zone, it is now clear that nutrients and water must to be managed together. The focus of water and nutrient management in the BMP era is now not only to produce vegetables profitably, but also to do so while conserving resources and minimizing the environmental impact of such production. As the development of Total Maximum Daily Loads (TMDLs) and Best Management Practices (BMPs) for vegetables grown in Florida takes place, growers are eager to find out how this process will affect their operations. TMDLs and BMPs have their origin in Federal and State legislations ([Table 1](#)). A TMDL is the maximum amount of a pollutant a water body can receive and still meet its water quality standards. BMPs are specific cultural practices that aim at reducing the load of a specific compound entering a water body, while maintaining economical yields ([Table 2](#)). Growers who will have a documented BMP plan will receive a waiver of liability, will be granted a presumption of compliance with water quality standards, and will be eligible for some cost-share programs available to partially refund the cost of BMP implementation. The BMPs applicable to vegetable production will be included in a new BMP manual for row crops and vegetables, which is currently under development by the Florida Department of Agriculture and Consumer Services (FDACS). Three types of BMPs for vegetable crops are described in this manual: the universal BMPs, the irrigation/engineering BMPs, and the water and nutrient management BMPs. In the BMP Manual for row crops and vegetables, BMPs are 1-to-3 page-long chapters that include a working definition of the topic, list specific things to do (BMPs) as well as things to avoid (pitfalls), and present existing applicable technical criteria together with additional references. This publication presents a summary of how principles of fertilization and irrigation for vegetable crops should be applied in commercial operations ([Table 3](#)). This document is not a substitute for current recommendation (see the Vegetable Production Guide for Florida at: http://edis.ifas.ufl.edu/TOPIC_GUIDE_Vegetable_Production_Guide_for_Florida) but should be considered an educational tool for the transition period into the BMP era.

65. *Simonne, E.H., Hutchinson, C.M., Dukes, M.D., Hochmuth, G.J., and Hochmuth, R.C. (2003). Update and Outlook for 2003 of Florida's BMP program for Vegetable Crops. Document HS916. Florida Cooperative Extension Service, Institute of Food and Agricultural Science, University of Florida, Gainesville.*

Original abstract: Not applicable.

Summary of Key Findings

Increased environmental concerns supported by reports of high NO₃-N and P levels in some springs and streams in Florida, have resulted in the passage of the Surface Water Improvement and Management (SWIM) Act of 1987. Together with the Federal Clean Water Quality Act of 1977, the SWIM Act created a program that focused on preservation and/or restoration of the state's water bodies through the development and implementation of Best Management Practices (BMPs). BMPs are cultural practices that should increase or maintain yields while being environmentally robust, economically feasible, and based on science and best professional judgment. BMPs are based on IFAS research results, and therefore, follow IFAS recommendations (Maynard and Olson, 2001). Florida growers, faced with the new BMP program, legitimately requested reliable data documenting the impact of current production practices on water quality. Much of this research has been completed as outlined in [Table 1](#). In this context, the goal of our multi-disciplinary research and extension program is to (1) actively participate in the development of the BMP manual, (2) develop research-based information supporting the efficacy of fertilization and irrigation BMPs, and (3) provide vegetable growers with recommendations and educational programs that help them comply with the new legislation. This paper outlines the current status of the BMP manual for vegetables, describes several research projects on the testing of possible BMPs for vegetable crops, and discusses challenges and opportunities for the implementation and adoption of the BMP program in Florida.

This publication provides information on the to-be issued "*Agronomic and Vegetable Crops BMP Manual for Florida*", which was later re-titled: "*Water Quality/Quantity Best Management Practices for Florida Vegetable and Agronomic Crop*" (see bibliographical citation No. 15 above).

66. **Simonne, E.H., and Hochmuth, G.J. (2005). *Soil and Fertilizer Management for Vegetable Production in Florida*. Document HS711. Florida Cooperative Extension Service, Institute of Food and Agricultural Science, University of Florida, Gainesville.**

Original abstract: "The Vegetable Production Guide for Florida was updated in December 2005. The most current version of this chapter may be found at <http://edis.ifas.ufl.edu/pdffiles/CV/CV10100.pdf> "

Summary of Key Findings

Through the implementation of a series of targeted cultural practices (the Best Management Practices [BMPs]) growers should be able to reconcile economical profitability and responsible use of water and fertilizer. At the field level, adequate fertilizer rates should be used together with irrigation scheduling techniques and crop nutritional status monitoring tools (leaf analysis, petiole sap testing).

The crop nutrient requirement (CNR) for a particular element is defined as the total amount in lb/A of that element needed by the crop to produce economic optimum yield. The CNR values are those amounts of nutrients needed to produce optimum, economic yields from a fertilization standpoint. Soil testing must be conducted to determine the exact contribution from the soil to the overall CNR. Based on such tests, the amount of fertilizer that is needed to supplement the nutrition component of the native soil can be calculated.

Additionally, once the nutrient content of the soil is known, the appropriate fertilizer can be utilized. Waste organic products contain nutrients that can enhance plant growth, however, its nutrient content and decomposition rate must first be determined to ascertain its appropriateness. Controlled-release fertilizers (CRFs) are more expensive than other types of fertilizers, but they may be useful in reducing fertilizer losses through leaching, in decreasing soluble salt damage, and in supplying adequate fertilizer for long-term crops. Starter fertilizers, used for establishment of young seedlings and transplants, represent a very small percentage of overall fertilizer amounts, but are very important in establishing crops in cool, damp soils. Foliar fertilization most appropriately applies to micronutrients but should be thought of as a last resort for correcting a nutrient deficiency.

It has been common in Florida vegetable production to routinely apply a micronutrient package. Compounding the problem has been the vegetable industry's use of micronutrient-containing pesticides for disease control. This situation has forced some vegetable producers to overlime in an effort to avoid micronutrient toxicities. Over liming results in high soil pH, which can tie up micronutrients and restrict their availability to the crop. Over liming also can reduce the accuracy with which a soil test can predict the fertilizer component of the CNR.

The goal of water management is to keep the irrigation water and the fertilizer in the root zone. Fertilizer rate and placement must be considered together and is done so in such techniques as the Linear Bed Foot system (LBF), which is based on typical distances between bed centers for each crop. The LBF's goal is to provide a specific concentration of nutrients to plant roots.

A drip-irrigation system can be used to supply adequate nutrition to each crop in a double crop system. Once the crop fertilizer requirements have been ascertained, the needed nutrient may be applied through the drip system. Many drip irrigation users have turned to fertigation (applying nutrients through the irrigation tube) to gain better fertilizer management capability. Nutrient management through irrigation tubes involves precise scheduling of applications which are determined by crop growth and resulting nutrient demand.

Analysis of plants for nutrient concentration provides a good tool to monitor nutrient management programs. There are basically two approaches to plant tissue testing: standard laboratory analyses based on dried plant parts, which can be very accurate but time-consuming; and the plant sap testing procedures, which offer speed in analysis but are less quantitative than lab procedures.

The use of cover crops and windbreaks can provide several benefits. The cover can slightly increase soil organic matter during the growing season and reduce soil losses due to erosion from both wind and water. Windbreaks used in agriculture are barriers, either constructed or vegetative, of sufficient height to create a windless zone to their leeward or protected side. Windbreaks are especially important to protect young plants which are more susceptible to wind damage. Abrasion to plants from wind-blown sand is of concern in most of Florida. Strips of planted rye are generally recommended for temporary windbreaks in central and northern Florida."

67. *Smajstrla, A.G., Boman, B.J, Haman, D.Z., Izuno, F.T., Pitts, D.J., and Zazueta, F.S. (1997). Basic Irrigation Scheduling in Florida. Bulletin No. 249. Institute of Food and Agricultural Services, University of Florida, Gainesville.*

Original abstract: "Proper irrigation scheduling is the application of water to crops only when needed and only in the amounts needed; that is, determining when to irrigate and how much water to apply. With proper irrigation scheduling, crop yields will not be limited by water stress from droughts, and the waste of water and energy used in pumping will be minimized. Other benefits include reduced loss of nutrients from leaching as a result of excess water applications, and reduced pollution of groundwater or surface waters from the leaching of nutrients. Irrigation is practiced to provide water when rainfall is not sufficient or timely to meet water needs of a crop. For most agricultural crops, yield or quality reductions result from water stress. Therefore, if water is available and if it is relatively low in cost, as is the case in Florida, irrigations are normally scheduled to avoid plant water stress. Despite Florida's large average rainfall of 52.60 inches per year, irrigation is practiced extensively. Irrigation is necessary because of the nonuniform distribution of rainfall, the very limited water-holding capacities of typical sandy soils, and the extreme sensitivity of many specialty crops to water stress. These factors and the economic losses from under-or-over-irrigation require that irrigations be scheduled as efficiently as possible. This publication discusses irrigation scheduling for crops grown on typical Florida deep sandy soils so that shallow water tables do not contribute to crop water use. Thus, irrigation events must periodically occur to replenish water in the crop root zone. Water budgeting for water table management on poorly drained soils, called subirrigation or seepage irrigation, is discussed in IFAS Extension circular 769, "Water Budgeting for High Water Table Soils", available from IFAS County Extension Offices. In seepage irrigation, water is applied to maintain a high water table just below the crop root zone."

Summary of Key Findings

Delivering water to a crop in the field results in losses which increase the amount of water that must be pumped to supply the crop water requirement. Irrigation can be minimized by anticipating rainfall and providing soil storage capacity (that is, irrigating to less than field capacity to leave room for rainfall storage when the probability of rainfall is high) to increase rainfall effectiveness. Proper irrigation scheduling will help to assure efficient use of water and energy in crop production.

Irrigation scheduling methods that are currently applicable in Florida are:

- 1) A water budget method requiring estimation of daily evapotranspiration (ET) and soil water content

The water-budget method is also called a water balance or bookkeeping procedure. If the balance on a starting date and the dates and amounts of deposits and withdrawals are known, the balance can be calculated at any time. The time when all funds (or water) would be withdrawn can be determined so that a deposit can be made to avoid an overdraft (or an irrigation can be scheduled to avoid water stress). The starting point for irrigation scheduling is often after a thorough wetting of the soil by irrigation or rainfall. This brings the soil reservoir to full capacity. Daily measurements or estimates of ET are subtracted from the available soil water until the soil water storage has been reduced to the allowable depletion level. At that point an irrigation should be applied with a net amount equivalent to the accumulated ET losses since the last irrigation. The soil reservoir is thus recharged to full capacity and the depletion cycle begins again.

The water budget procedure also accounts for rainfall. If large rainfalls occur, only that portion required to restore the soil water content to field capacity will be effective. Greater amounts of rain will either run off of the soil surface or drain below the plant root zone. The management decision concerning the level of allowable water depletion (AWD) is one that must be made by each irrigation manager.

- 2) The use of soil moisture measurement instrumentation

The most common soil moisture measurement device used for scheduling irrigations is the Tensiometer. This instrument registers the status of water in the soil, in terms of soil-water tension, at the depth at which the device is placed. Soil-moisture monitoring instruments, including the Tensiometer are most effectively used in combination with ET data. The instruments are read to determine when to irrigate, and the ET data are used to calculate the volume of water lost since the last irrigation. From this, the volume of water to be replaced can be determined.

Good farm irrigation management requires that an irrigation system be capable of applying water in sufficient quantities to meet the crop's water requirements and with high uniformity to minimize waste. When properly used and combined with efficient methods of water application, these techniques should also result in increased production and profits.

68. *Soil and Water Engineering Technology (1994). Leakage Detection and Mitigation for Dairy Waste Lagoons and Storage Ponds. FDEP 319(h) Contract No. WM507; Final Report. Tallahassee, FL.*

Original abstract: "The potential for ground water contamination by leakage from earthen dairy waste storage ponds has been previously demonstrated. In this project a new technique for the direct measurement of storage pond seepage was developed and implemented, corroborating initial seepage estimates. An experimental low volume scavenger well was installed near a dairy waste storage pond and extracted nitrogen at rates approximating leakage loading rates. Directly measured pond seepage rates were $2\text{E-}7$ m/sec, corresponding to an average nitrogen mass loading of 4.3 kg/day. The scavenger well extracted nitrogen at an estimated average rate of 5.3 kg/day. The results indicate extraction of ground water near leaking dairy waste storage ponds may be a cost effective alternative to retroactive lining of ponds in appropriate hydrogeological terrains. The net cost benefit derived by the reduced cost of scavenger well installation and operation compared to that of new pond construction could be applied to the implementation of other beneficial management practices. Interception techniques derive the additional benefit of extracting residual nutrients from the surficial aquifer that may have been introduced by other farm management practices."

Summary of Key Findings

The analysis was conducted on a dairy waste holding pond in Lafayette County, Florida. A groundwater quality monitoring network consisting of seven wells and a low-volume scavenger well were installed in the vicinity of the pond. This network is a technique known as groundwater interception. The method is based upon creating a capture zone by pumping one or more wells down gradient of a plume. While not appropriate in all hydrogeologic settings, interception is attractive as an alternative to retroactively fitting dairies with lined ponds. As an aid to the design of the interception networks, the authors created a new apparatus and thereby a novel technique for the direct measurement of storage pond seepage.

Groundwater samples were drawn from the monitoring network and the scavenger well for the testing of total Kjeldahl nitrogen, ammonia, nitrate-nitrite and phosphorous. Monitoring network samples were extracted with a peristaltic pump

through dedicated nylon tubing installed in the seven wells. Scavenger well samples were collected in stream.

The authors found that seepage from the unlined earthen dairy farm waste holding pond loaded surficial groundwater at an appreciable rate. However, concentrations tended to decrease significantly with distance.

A well-designed and well-constructed pond liner may reduce the amount of nutrient loading to the groundwater by that pond, though it is not clear that pond lining guarantees that total nitrogen loading of the groundwater by the dairy will be significantly affected. In appropriate hydrogeological settings, extraction of groundwater near seeping ponds may be far more cost effective than retroactive pond lining. The net cost benefit derived by the reduced expense of scavenger well installation and operation compared to that of new pond construction could be applied to the implementation of other beneficial management practices.

There are many compelling reasons for the installation of concrete ponds and lagoons when a new dairy is being constructed, such as increased ease control over waste management and potentially enhanced groundwater protection. Moreover, a well-designed and well-constructed retention structure certainly is less prone to leakage than many simple earthen ponds. However, retrofitting existing dairies with lined ponds simply is not cost effective in terms of the protection of groundwater quality. The incremental cost of retrofitting existing ponds is substantially greater than the incremental cost of opting for a lined pond at time of dairy construction. The authors determined that implementing a leachate interception well, where water flows to a well down gradient of a contaminant plume, would provide acceptable protection at a lesser cost.

69. *Soil and Water Engineering Technology (1995). Effectiveness of Various Components of a Dairy Waste Management System for Controlling Nitrogen and Phosphorous Losses to Surface and Ground Water. FDEP 319(h) Contract No. WM564; Final Report. Tallahassee, FL.*

Original abstract: "This project represents the monitoring/BMP evaluation phase of a renovated Dairy Waste Management System completed under a companion agreement with the Natural Resources Conservation Service (NRCS) WM482. The project's objective was to determine the effectiveness of various components of a dairy waste management system in the control of N and P losses to surface and ground water in a karst environment (Middle Suwannee River Basin). The project also was intended to provide verification of the basic design assumptions used to develop and size various elements (BMPs) of the system. Significant results of the project include: The N and P content of lactating cow manure was found to be higher than current literature design values. This needs to be considered in the design of animal waste management systems, especially the land application component. Lactating cows will

defecate about 12 times per day and urinate about 8 times a day with urination frequency increasing during warmer weather. Lactating cows were found to defecate and urinate at about the same frequency throughout the dairy, thus giving credence to the assumption that the percent of time spent in an area will be equal to the percent of manure deposited. A small amount of N and P are lost in the sand trap and a storage pond with a short detention time of about four days. Most of the N lost in a waste storage system with a detention time of less than seven days occurs during land application of spray effluent with total N losses being greater than 40%. Phosphorus is more conservative and moves through the waste management system to the spray field with minimal losses (<5%). Atmospheric losses of N (volatilization) from raw feces appear to be small over the first 30 days of deposition, but high variability limits conclusions. Volatilization losses of N from urine were extremely high for both soil (91% for 30-day N loss) and hard surface (97% for 30-day N loss) deposition areas. Nearly half of these losses occurred within 24 hours. Use of N:P ratios for soil-matrix volatilization pans (SVPs) is unreliable and should be reevaluated for future studies."

Summary of Key Findings

The long-range objective of this project is to prevent water quality problems from dairy waste management systems while optimizing the use of waste for farm profitability. The authors set out to gain a better understanding of spatial and temporal manure deposition patterns and how the two primary nutrients of concern in animal waste, nitrogen (N) and phosphorus (P), are deposited, transformed, and transported through the various components of a dairy waste management system.

The authors evaluated one Florida dairy waste management systems' performance with regard to nutrient management. Eight tasks were designed in order to better ascertain the strength of the dairy's performance:

1. Estimate the N and P content in manure generated by the lactating herd on a dairy.

Three separate methods were used to estimate the nitrogen (N) and phosphorous (P) content in manure generated by the lactating herd on the dairy for four different times of year. They were: 1) literature values for manure content and production, 2) nutrient balance based on feed consumption and milk exports, and 3) direct measurement of discharge from the milk barn (done in Task 3). The results of these three methods for determining the N and P in manure were then compared for accuracy.

2. Determine the amount of raw manure deposited in all areas accessible to the lactating cow herd.

The spatial and temporal distribution of manure deposited by the lactating cow herd was determined during four 24-hour monitoring periods (runs). The four runs were done to observe potential seasonal variations due primarily to temperature. Manure deposition was determined by observers, located outside the staging areas, counting the number and recording the location of the defecations and urinations every 15 minutes for all cows in one lactating herd. A count of the actual fresh feces piles found in the pasture was conducted at the end of the 24-hour monitoring period as a means of determining recording accuracy.

The inability to observe all defecations is a problem that needs to be addressed if this type of study is repeated. The manure deposition counts were probably poorest in the pasture because of the larger area to be covered by an observer and excretions are quieter on the thick grass as compared to concrete.

3. Measure the amount of N and P entering the waste management systems from the manure collection area(s) and compare to Task 2's results for the relative amount of manure being deposited in the collection system (milk barn).

The amount of N and P deposited in the milk barn and subsequently entering the waste management system was measured at the milk-barn flush-water collection ditch just upstream of the sand trap/solids separator. Approximately, one composite sample was collected for every herd milking. All samples except those collected for solids analysis were analyzed for total Kjeldahl nitrogen (TKN) and total phosphorus (TP). Samples analyzed for solids had results in terms of total solids and total volatile solids. The ammonia concentration was also determined for the barn wash samples collected during runs one, two and four.

The measurement technique used for estimating the manure N and P being flushed from the milk barn was very labor intensive but produced good results. The weir placed in the discharge ditch between the milk barn and sand trap provided accurate measurements of the volume of water being discharged. This sampling point represented 100 percent of the waste entering the waste management system. The dynamics of the flow corresponds directly to dairymen's procedure for washing the cows and rinsing the floors.

4. Measure the amount of N and P contained in solids removed in e solids separator.

The amount of solids and associated N and P removed in the sand trap were estimated based on samples collected within the sand trap and assumed solid removal rates. The actual volume of the solids removed in the sand trap could not be measured directly, because of the soupy nature of the solids prevented complete cleaning of the trap with the available farm equipment. Therefore, assumed removal

rates of 10, 20 and 30 percent were used. The solids entering the sand trap were estimated by using the ASAE standard values and the percent time cows spent in the milk barn, which produced an estimate of about 980 lb/day.

5. Measure the amount of N and P contained in effluent pumped from the waste lagoon and compare them to inflows as calculated in Task 3 and 4.

The procedure for determining the amount of N and P applied to the spray field at the dairy consisted of measuring the volume pumped using storage pond volume changes and collecting samples of the storage pond effluent at two locations: the discharge side of the irrigation pump at the storage pond, and at the ground surface after the effluent had been sprayed from the pivoting spray gun. The total quantity of N and P going to the spray field was then calculated from the nutrient analyses of these samples and the volume change of the waste storage pond during the pumping event.

Using an average of the increased N and P for the pumped and applied estimates, the nutrient applications rates produced an estimated annual loading to the spray field (about 50 acres) of about 550 lb/ac of N and 130 lb/ac of P. The observed nutrient application rates are within typical design parameters for a cropped spray field.

6. Measure the atmospheric losses of land-applied waste effluent for a period of 30 days after application.

Soil matrix volatilization pans (SVPS) were used to estimate the atmospheric losses of N that occurs after waste pond effluent is applied to the land. The total N and P remaining in the SVPs after 1, 7, and 30 days were compared to the initial amounts placed on the pans to estimate volatilization losses. Most of the observed N loss occurred within the first 7 days. Actual N volatilization rates in a real field will be highly dependent on rainfall. The authors suggest that small application depths be considered if excess N is a problem.

7. Measure the atmospheric losses of land applied raw manure (urine and feces) in a pasture/holding area for a period of 30 days after application.

The atmospheric losses in raw manure dropped by the cows in an open pasture or lane area was determined in the same fashion for the spray field effluent samples. The SVP pans were again used but with raw urine and feces samples. Bulk feces and urine samples were collected at the same time the spray field samples were collected. The very high variability of the N analyses for feces limited the usability of the data, but there appeared to be no large losses of N from feces over the 30-day period. Urine exhibited a very high evaporation rate. The 7-day loss of P for run 1 was about 73%, and a 50% loss of N, the 30-day loss of P for the second run was about 65% and the

loss of N was about 98%. The mechanism for the loss of P is unclear, but likely due to either strong adsorption or crystallization of P on the bucket surfaces which prevented full recovery of the P when samples were collected. It is suggested that an acid wash of the bucket be analyzed in the future.

8. Develop an N and P balance of the various components of the waste management system and present the removal and transport efficiencies.

The N and P balance on the dairy was determined by using the measured or estimated results of the Task 1 through 7 for the various components of the dairy waste management system. The majority of N loss in the waste management system is occurring after the field application. The sand trap and waste storage pond appear to have limited N removal. The SVP results clearly show that rainfall can reduce N losses. The P appears to be moving through the waste management system without significant losses.

The authors, with the caveat that since just one dairy was analyzed extrapolation of these results to other dairies should be done cautiously until additional data for other dairy conditions are available, were able to come to the following conclusions:

1. The N and P content of lactating cow manure was found to be higher than current literature design values.
2. Lactating cows will defecate about 12 times per day and urinate about 8 times a day with the urination frequency increasing during warmer weather.
3. Lactating cows were found to defecate and urinate about the same frequency throughout the dairy, thus giving credence to the assumption that the percent of time spent in an area will be equal to the percent of manure deposited.
4. A small amount of N and P are lost in the sand trap and a storage pond with a short detention time (about 4 days).
5. Most of the N lost in a short detention time (less than 7 days) waste storage system is after land application of spray effluent with total N losses being greater than 40%.
6. Phosphorus is more conservative and moves through the waste management system to the spray field with minimal losses (less than 5%).
7. Atmospheric (volatilization) losses of N from raw feces appear to be small over the first 30 days after deposition, but high variability in the data limited conclusions.
8. Atmospheric (volatilization) losses on N from urine were extremely high for both soil (91% for 30-day N loss) and hard surface (97% 30-day N loss) deposition areas. Nearly half of these losses occurred within 24 hours.
9. The majority of atmospheric losses will occur within 30 days of land application because the nitrification process will have converted the majority of the remaining ammonia by this time.

10. Use of N:P ratios for the soil-matrix volatilization pans (SVPs) is unreliable and should be reevaluated for future studies.

70. *Soil and Water Engineering Technology (1998). GIS Watershed Assessment Final Report; Part C- BMP Guide. Tallahassee, Florida.*

Original abstract: Not Applicable.

This document provides the following introduction: "This document provides a series of best management practice (BMP) guides for the land uses within the Suwannee River basin that have been identified as high pollutant source areas. The guides contain general information on the available BMPs for each land use and provide references containing more detailed sources of information. The guides discuss which BMPs are most appropriate for different situations. A rough estimate of the relative costs and pollutant removal efficiencies is also provided.

In some cases, these guides are constructed so that they could be removed and used as independent documents. These separate guides can then be provided to land owners with the land use of interest. In other cases, where good documents are already available for a particular land use, or BMP, then only a brief summary is provided with a reference to the more complete document.

Best management practices (BMPs) are methods, measures, or practices designed to prevent or reduce pollution. They include operation and maintenance procedures as well as structural and nonstructural controls. The four general approaches to control nonpoint-source pollutants are structural controls, source controls, land management, and integrated pest management."

Of relevance to agricultural BMPs, this document provides guides on: (i) crop fertilizer management, which includes practices to control nitrogen and phosphorous losses; (ii) agricultural erosion control; and (iii) animal waste management. The animal species include: poultry, swine, beef cattle, dairy cattle, horses, sheep, and goats.

Summary of Key Findings

Included in this report is a table (Table 7) that summarizes all of the BMPs that are mentioned in the entire document. The BMPs are evaluated for their relative effectiveness and cost, which are given in scaled terms of "high", "medium", and "low". Crop fertilizer management BMPs are all given a effectiveness score of "high" with a corresponding cost rating that ranges from "high" to "low". The agricultural erosion control BMPs effectiveness and cost score range evenly from "high" to "low", and the animal waste management BMPs effectiveness and cost also range evenly from "high" to "low"; however, the animal waste treatment BMPs (i.e., composting, waste storage pond, and land application of pond water) are all given a score of "high" for both effectiveness, and cost.

71. *Suwannee River Soil and Water Conservation District (1998). Demonstration of On-Farm Composting of Dairy Manure. FDEP 319(h) Contract No. WM571; Final Report. Tallahassee, FL.*

Original abstract: "The Middle Suwannee River Basin is a very vulnerable area for ground water contamination. Evidence suggest that nitrate concentrations in springs in the river have increased in recent years, perhaps as a result of agricultural land use activities. Dairy cow numbers and poultry operations continue to expand while land area for manure spreading is decreasing. Some dairy farms do not have sufficient land on the dairy to properly use their animal waste at rates that do not exceed crop needs. This project was intended to demonstrate on-farm composting of dairy manure as an alternative waste disposal method. Composting has been embraced by other types of animal husbandry operations such as the broiler industry. However, due to the high percent moisture associated with dairy manure this technique has not been well accepted as an alternative practice by the industry. The results demonstrate that it is possible to produce a relatively dry, easily transported material for use in remote locations in about ten days. Unlike raw manure it can be transported in dump trucks over public roads to outlying fields removed from the main dairy itself. On-farm composting can be a cost effective solution for other dairies that need to export nutrients off their farms to solve environmental problems."

Summary of Findings

The objective of this project, which was initiated on January 22, 1996, and ended on August 14, 1998, was to demonstrate on-farm composting of dairy animal wastes as an alternative waste disposal method. The need for such alternative methods of waste disposal was prompted by past research that indicated that dairy farm waste disposal operations conducted within the Middle Suwannee River Basin (MSRB) contributed significantly to nitrate-nitrogen contamination of the Floridan Aquifer (a major source of local drinking water). The effectiveness of this demonstration project was based upon the belief that composted animal waste from dairies could be used as a fertilizer on forage crop fields. The project's mission was to demonstrate that on-farm composting of dairy manure was economically feasible, and that it offered a long-term cost-effective manure disposal alternative that would protect and improve ground water quality. The initial tasks of the project included the planning, design, inspection, and certification of the composting bin, composting barn, curing barn, and loading ramp. These initial tasks were completed by the USDA Natural Resources Conservation Service (formerly, the USDA Soil Conservation Service).

Over the course of the project, several operational problems surfaced, which were either resolved as part of the project or expected to be resolved in the future. It was found that unlike raw manure, the composted manure could be transported in dump

trucks over public roads, and used in a variety of ways. The resulting benefits of on-farm dairy waste composting included:

- use as a soil amender before crops are planted;
- use as a nutrient source for crops; and
- use as a nutrient export medium for the originating dairy farm.

72. *Suwannee River Soil and Water Conservation District. (1999). Suwannee River RC&D Strip Till 319 Project. FDEP 319(h) Contract No. WM632; Final Report. Tallahassee, FL.*

Original abstract: "The Suwannee River watershed is characterized by sandy soils, karst geology, and extensive agricultural lands. To minimize nonpoint source pollution from agricultural croplands, especially sediments, this project was undertaken to promote conservation tillage. The project consisted of the purchase, by the Suwannee River RC&D, of two KMC Rip/Strip Units and two Donahue Trailers to loan to area farmers as an incentive to use conservation tillage. To educate area farmers about the benefits of strip tillage, a series of six field days were held in Madison, Hamilton, and counties. Additionally, the RC&D worked with local cooperators to establish four on-farm demonstration plots for different crops including corn, cotton, and peanuts. Overall, the goals of the project were achieved with conservation tillage increasing in the watershed. Unfortunately, a three year drought and changing cropping patterns reduced the anticipated use of the strip till equipment. However, with the increases in forage crops associated with dairies in the basin, the RC&D anticipates increased interest in the use of their equipment and conservation tillage practices in general."

Summary of Key Findings

Sediment from cropland can carry organic matter, nutrients, and pesticides that may adversely affect the quality of the Suwannee River. This project addresses the need to demonstrate to farmers the benefits of adopting conservation tillage and reducing runoff from cropland during storm events. Strip-till creates a row of tilled ground approximately 10" wide for planting. In between these strips of tilled soil, the previous crop residue is left undisturbed. This results in less water runoff, reduced soil erosion/sedimentation, improved fertility, better moisture conservation and improved pesticide effectiveness. These practices will increase crop yields, which will enhance the farmer's sustainability, while at the same time protect the environment.

The Suwannee River Resource Conservation and Development Council (SRRC&D) proposed that purchasing reduced tillage equipment, with Environmental Protection Agency (EPA) 319 program funding, and loaning it to farmers for their use and evaluation would result in increased education and BMP implementation. By providing strip-tillage equipment for demonstration, use and evaluation it is expected

that crop acres enrolled in conservation tillage will increase and water quality will improve as a result.

Overall, the goals of this project were achieved as well as some other positive results. Due to a 3-year spring drought and changing cropping patterns the amount of acres put in strip till with the purchased equipment was limited. The Suwannee River RC&D was successful in holding four Conservation Tillage Field Days in the project area as well as two field days in other counties that were well attended. A variety of speakers discussed topics such as keys to successful strip tillage, cover crop and weed management, sprayer calibration and drift reduction strategies, pesticide storage and mixing/loading BMPs and cost share programs available for implementing strip tilling on the farm. Additionally, new Pesticide and Equipment Maintenance BMP Manuals were distributed.

The SRRC&D worked with local cooperators in establishing four on farm demonstration plots. The demonstration plots were on corn and cotton, corn, and peanuts at the respective farms. The strip tilled corn plots seemed to hold up better under the severe drought and heat stress and were able to go longer between irrigations. The cotton plots seemed to have grown off better than the conventional plots but more rain was needed to finish out the crop. Although yield data is not available as of yet, preliminary estimates by the farmers indicated that strip-till has equaled or exceeded conventional tillage in growth and appearance.

The authors found that conservation tillage acres were increasing in the RC&D coverage area though traditional row crop acreage was declining. Conservation tillage can be one tool that can play a role in reducing crop inputs while maintaining yields. The ultimate success of this project will depend on small victories in changing farmers' minds and encouraging them to try a different approach. The Suwannee River RC&D conclude that this project has provided the needed tools to continue to strive toward this goal.

73. *Thomas, M.V. and E.H. Livingston. 1999. A Cooperative Program for Reducing NPS Pollution in a Florida Agricultural Watershed. Presented at the 1999 ASAE/CSAE-SCGR Annual International Meeting, July 18-21,1999, Toronto, Ontario, Canada. ASAE Paper No. 992187. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659 USA*

Original abstract: "The Total Maximum Daily Load (TMDL) program requirements of the federal Clean Water Act are requiring states to develop new initiatives for managing agricultural nonpoint pollution sources and for measuring the use and effectiveness of nonpoint source controls. In Florida's Middle Suwannee River Basin, public agencies and the agricultural community are taking the lead in implementing a watershed-based process for development, demonstration, refinement, and implementation of best management practices (BMPs) to reduce nutrient loadings to

ground water and surface water, involving stakeholders throughout the basin. These cooperators have formed the Suwannee River Basin Nutrient Management Working Group (SRBNMWG). Ensuring community understanding that nonpoint source pollution is everyone's problem and that everyone must be part of the solution has been the key to success. Five technical subcommittees have been set up to work with the three primary sources of non-background nitrates: human waste management (domestic, industrial, and stormwater), animal waste management, fertilizer management, and two additional committees for monitoring and education. Methods of attack vary from public education and university research to best management practices, cost sharing, and new legislation to enable regulatory incentive programs. More than \$7.5 million have been committed to this effort through state, federal, local, and private funding."

Summary of Key Findings

This paper provides a general overview of the reduced chemical integrity of surface and groundwater resources within the Middle Suwannee River Basin due to nitrogen and phosphorous contamination associated with agricultural practices, and how the problem is being addressed by public agencies and the agricultural community. Of particular importance is the formation of the Suwannee River Basin Nutrient Management Working Group (SRBNMWG), whose stated mission is to: "Assess sources of nutrient load to the Suwannee River Basin and optimize reductions in loadings to waters of the basin emphasizing voluntary, incentive-based programs for protecting the environment and public health." A variety of public agencies and non-public organizations are signatories of the SRBNMWG. In addition, any individual that wishes to participate or contribute is welcomed in the group. The general SRBNMWG membership comprises stakeholders, concerned citizens, and five technical working groups that specialize in specific technical fields. The technical working groups include the:

- Fertilizer Management Technical Working Group;
- Animal Waste Management Technical Working Group;
- Human waste Management Technical Working Group;
- Monitoring and Research Technical Working Group; and
- Education and Outreach Technical Working Group

Each technical group works within the context of specific objectives and responsibilities. For example, one of the objectives of the Fertilizer Management Technical Working Group is to "determine current practices and the effectiveness and extent of current BMPs"; another is to "evaluate and test new BMPs and modifications to existing BMPs that are technically and economically feasible".

74. Van Horn, H.H., Newton, G.L., Nordstedt, E.C., Kidder, G., Graetz, D.A., and Chambliss, C.F. (1990). *Dairy Manure Management: Strategies for Recycling Nutrients*

to Recover Fertilizer Value and Avoid Environmental Pollution. Document CIR1016. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville.

Original abstract: Not applicable.

Summary of Key Findings

"Concerns regarding nutrient losses from the manure of large dairy herds to groundwater or surface runoff have been extremely acute in Florida. The most widely publicized concerns have been with phosphorus (P) contamination of Lake Okeechobee, probably washing off the farms in surface runoff during the summer rainy season. Also of concern are nitrogen (N) losses in the form of nitrate into the groundwater through the deep sandy soils of the Suwannee River basin. Florida is not unique. All states are starting to monitor farms where large numbers of food-producing animals are maintained on small acreage. But regardless of farm size, maintenance of the environment and efficient utilization of nutrients should be a priority. Nitrogen (N) and phosphorus (P) are the primary nutrients of concern. Manure N can be converted to nitrates in the soil and potentially leach to groundwater. Manure P can potentially move with surface runoff, thus stimulating algae and aquatic plant growth leading to eutrophication of surface waters. Potassium (K) has not been of as much concern environmentally as N and P, but it is of equal concern in fertilizer management strategies. Also, K is important in assessing equivalent commercial fertilizer value of manure. Manure nutrients and decaying organic matter are natural components of the environment that ultimately contribute to the production of more plant and animal tissue. Thus, concern about manure leakage is no different than concern about commercial fertilizer use. Manure is in fact a resource, based largely on its equivalence with commercial fertilizer, and should not be called a waste when it is recycled through new plant growth. To use the resource value of manure effectively and to avoid excessive concentration of these nutrients at inappropriate points, it is helpful to budget nutrient flow through the total dairy farm system. If there is a problem concentration at some point, then corrective measures can be taken which are environmentally accountable. To do this, quantitative information is needed on nutrient flow through all segments of the system. Critical questions are:

How much of individual nutrients is excreted by dairy cows? (See page 2.)

How does the manure management system affect nutrient flow and nutrient recoveries for fertilizer use? (See page 4.)

What is the potential nutrient removal by plants? (See page 7.)

How do you develop a manure nutrient budget? (See page 8.)

What steps help to document environmental accountability? (See page 14.)

This publication is designed to give background information and serve as a guide to dairy farmers and planners to help develop answers to these questions for an individual dairy farm."

75. Van Horn, H.H., Wilkie, A.C., Powers, W.J., and Nordstedt, R.A. (1994). *Components of Dairy Manure Management Systems*. J Dairy Sci 77:2008-2030.

Original abstract: "Dairy manure management systems should account for the fate of excreted nutrients that may be of environmental concern. Currently, regulatory oversight is directed primarily at the assurance of water quality; N is the most monitored element. Land application of manure at acceptable fertilizer levels to crops produced on the farm by hauling or by pumping flushed manure effluent through irrigation systems is the basis of most systems. Nutrient losses to surface and groundwaters can be avoided, and significant economic value can be obtained from manure as fertilizer if adequate crop production is possible. Dairies with insufficient crop production potential need affordable systems to concentrate manure nutrients, thereby reducing hauling costs and possibly producing a salable product. Precipitation of additional nutrients from flushed manures with sedimented solids may be possible. Composting of separated manure solids offers a possible method to stabilize solids for distribution, but, most often, solids separated from *dairy* manures are fibrous and low in fertility. Manure solids combined with wastes from other sources may have potential if a marketable product can be produced or if sufficient subsidy is received for processing supplementary wastes. Solutions to odor problems are needed. Energy generated from manure organic matter, via anaerobic digestion, reduces atmospheric emissions of methane and odorous compounds. Use of constructed wetlands or harvesting of photosynthetic biomass from wastewater has the potential to improve water quality, making extensive recycling possible.

Summary of Key Findings

This research evaluated the nutrient cycling of N, P, and K through various methods of manure management. The primary steps in manure management include 1) predicting the amount and composition of manure produced, 2) separating manure solids from liquid, 3) distribution of manure solids for reuse or energy recovery, 4) reuse or treatment of liquid effluent, and 5) offsite disposal of excess manure byproducts. BMPs for each of these discrete steps were identified.

BMPs for manure composition and production:

- Avoid feeding cows diets that exceed nutrient requirements.

BMPs for manure separation:

- Reduce the volume of manure slurry by utilizing scraping rather than flushing with water.
- Screen separation methods result in more manure fertilizer nutrients remaining with the effluent.
- Vibrating screens result in 14-70% organic removal, 2-50% N removal, and 2-60% P removal.
- Wet screens result in 24% organic removal, 9% N removal, and 3% P removal.
- Sedimentation separation methods allow greater recovery of nutrients within the solids.
- Wastewaters need to be held 10-20 minutes to allow for adequate settling
- Flocculating agents like CaCO_3 can be used to increase sedimentation of solids and nutrient.

BMPs for Reuse of manure solids:

- Nitrification inhibitors can be used to reduce the leaching of NO_3 to groundwater during injection or plowing of manure solids.
- Use nutrient budgeting techniques to plan the amount of crop acreage needed to utilize manure
- Anaerobic digestion of solids reduces volume and produces usable effluent
 - o Reuse lagoon effluent to reduce potable water usage.
 - o Periodic sludge removal is necessary to minimize high nutrient sludge in lagoon effluent.
 - o Do not dispose of trash, water feed, spilled silage, or hay in treatment lagoons.

BMPs for use of liquid/effluent:

- 12.1 ha (30 acres) of spray field is necessary for adequate crop production to utilize N from 100 cows.
- If there is not adequate crop production to utilize nutrient through irrigation, manure flushing practices should not be used.
- To reduce the amount of liquid produced:
 - o Scrape or haul manure from high use areas (e.g. feeding barn or milking room floor) for offsite management.
 - o Use wastewater rather than freshwater to flush manure.
 - o Use a housing system that keeps cows clean enough to eliminate cow washers prior to milking.

BMPs for effluent that must meet regulatory standards:

- Chemical treatment (precipitation with FeSO_4) reduces P in effluent waters.

- Constructed wetlands can be used to remove excess nutrients in effluent to meet regulatory standards.
- Use effluent as a growth medium for micro algae which improves water quality and can be used as animal feed or fertilizer.

76. Van Horn, H.H., Newton, G.L., and Kunkle, W.E. (1996). *Ruminant Nutrition from an Environmental Perspective: Factors Affecting Whole-Farm Nutrient Balance*. *J. Anim. Sci.* 74:3082-3102.

Original abstract: "Nutrient budgeting strategies focus primarily on recycling manure to land as fertilizer for crop production. Critical elements for determining environmental balance and accountability require knowledge of nutrients excreted, potential nutrient removal by plants, acceptable losses of nutrients within the manure management and crop production systems, and alternatives that permit export of nutrients off-farm, if necessary. Nutrient excretions are closely related to nutrient intake and can be predicted by subtracting predicted nutrients in food animal products exported from the farm from total nutrients consumed. Intensifying crop production with double-or triple-cropping often is necessary for high density food animal production units to use manure without being forced to export manure or fertilizer coproducts to other farms. Most manures are P-rich relative to N largely because of 1) relatively large losses of volatilized NH₃, most of it converted from urea in urine, 2) denitrification losses in soil under wet, anaerobic conditions, and 3) ability of many crops to luxury-consume much more N than P. Most soils bind P effectively and P usually is permitted to accumulate, allowing for budgets to be based on N. However, P budgeting may be required in regions where surface runoff of P contributes to algae growth and eutrophication of surface waters or where soil P increases to levels of concern. Research is needed to determine whether dietary P allowances can be lowered without detriment to animal production or health in order to lower P intake and improve N:P ratios in manure relative to fertilization needs."

Summary of Key Findings

This research evaluated nutrient budgeting strategies to reduce manure and nutrient production and increase utilization of nutrients once they are produced. Nutritional management through correct selection of feed ingredients, ration balancing, and the judicious use of performance and feed efficiency-enhancing products is the most economical first step in managing whole-farm nutrient streams.

Recommended BMPs to reduce nitrogen and phosphorus inputs include:

- Eliminate dietary excess. For example, reduce P to NRC (1989) recommendations.
- Feed high protein diets only during early lactation. Revert to normal diet during mid- and late-lactation.

- Use animal nutritional physiology models (e.g. Cornell Net Carbohydrate and Protein Model) to estimate changes in excrement based on changes in diet.
- Balance ruminally degradable and nondegradable protein reduce N.
- Reduce manure volume with higher digestibility diets.
- Use feed additives that increase productivity to reduce manure production per unit of animal product production.

In evaluating field application of manure slurry, this research used flushed manure slurry, screened to remove large particles. The liquid was applied through a center pivot irrigation system at 7d to 21d intervals.

Recommended BMPs to increase nitrogen and phosphorus uptake:

- Increase P removal of crops by avoiding moisture stress and deficiencies in other nutrients
- Utilize the soil binding capacity for nutrients like P to maximize the life of land application sites.
- Utilize continuous cropping (i.e. triple crop rotation) and frequent application of relatively low amounts of manure to reduce leaching from the plant root zone.

This research evaluated the grazing management for dairy cattle and the associated effects on nutrient cycling. In general, intensive dairy grazing led to a greater recycling of nutrients; however, supplemental N in the form of commercial fertilizer or legume crops would be needed to maintain sustainability. No supplemental P is required once soil storage levels reach desired fertility levels.

77. *Van Horn, H.H., Newton, G.L., French, E.C., and Nordstedt, R.A. (1998). Managing Dairy Manure Accountably: Worksheets for Nutrient Budgeting. Document CIR1196. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville.*

Original abstract: Not applicable.

Summary of Key Findings

Manure is well recognized for its fertilizer value but the value of manure is not often directly calculated. It has often been assumed that recovery costs were greater than value and manure nutrients were not fully utilized. However, unused manure N or P may leak to surface or groundwaters. Thus, environmental concerns mandate manure utilization regardless of costs. The plan for utilization needs to use manure resource value to pay for its implementation to the fullest extent possible. This circular is directed to producers to help them develop manure nutrient management plans. Dairy advisors also are expected users. The worksheets are designed for use as a computer spreadsheet to invite easy recalculation to look at alternative plans.

Background information can be found in University of Florida Cooperative Extension Circular 1016.

As stated in this "how to" publication, its objectives are to:

1. To show you and, perhaps, your urban neighbors what happens to manure and manure nutrients on your farm. It helps to document that you are not polluting or to identify needed improvements.
2. To predict crop production (acreage and yields) needed to recycle manure nutrients and limit losses to waters and atmosphere to environmentally acceptable amounts.
3. To identify dollar value of manure nutrients recovered that help pay for costs to manage manure in an environmentally acceptable manner.
4. To determine if or how many manure nutrients must be exported off-farm."

The worksheets provided in this publication include:

- (a) Worksheet 1: How much N, P, K, and DM are excreted?
- (b) Worksheet 2: How much of the excreted nutrients do you recover for fertilizer?
- (c) Worksheet 3: Budgeting use of recovered manure nutrients

The summary included at the end of this publication states the following:

- Nutrient excretions by lactating dairy cows, especially N and P, are easily estimated accurately when DMI, nutrient composition of the diet, and milk yields are known.
- Dairy producers must quantify manure nutrients recovered from the waste management system to accurately develop a whole-farm nutrient budget. That means weighing loads of manure, measuring gallons of wastewaters used in irrigation, and having samples analyzed for nutrient composition.
- Losses of more than 50% of the excreted N are common. If an average recovery must be used for preliminary calculations, we suggest that 40% be used, i.e., 60% lost. Losses of P should be less than 10%, and losses of K should be less than 20%.
- Manure nutrient applications for fertilizer are usually of less risk to the environment than equal nutrient applications of commercial fertilizer because enough of the recovered manure N is in organic form to lessen risk of leaching.
- Most dairy manure budgets find enough P to fertilize two to three times as many acres of crop production based on P as can be fertilized appropriately with manure N.

- Pasture budgets will almost always show need for supplemental N from commercial fertilizer N with no supplemental P needed from commercial fertilizer.
- Practical goals to realize the most value from dairy manure usually include: 1) reducing dietary P to NRC requirements to reduce diet cost and manure P excretion; 2) applying manure based on P budgets; and 3) applying manure to growing crops as soon as possible after excretion to minimize N volatilization losses. "

79. ***Walker, M.L., Nair, V.D., and Graetz, D.A. (2001). Analytical Protocol for Degree of Phosphorus Saturation Determination in Sandy Soils. ASA/SSSA/CSSA Annual Meeting Abstracts. 2001. (C.D. Rom publication).***

Original abstract: "Recent studies suggest that the Degree of Phosphorus Saturation (DPS), which relates extractable P to the sorbing capacity of the soil, may be a good indicator of the potential of manure-impacted soils to release phosphorus. However, DPS methodology involves determining oxalate-extractable P, a soil test not commonly performed in many laboratories in Florida. Assessing P saturation through routine agronomic soil tests (i.e., Mehlich 1) might make DPS a more convenient tool for predicting P leaching potential. Our objectives were to use different soil test methods to calculate DPS and to compare these results to DPS determined using oxalate extraction. Over 400 surface and subsurface horizons of sandy soils from four dairies in North Florida were analyzed for P, Fe, and Al using ammonium oxalate, Mehlich 1, and Mehlich 3 extractants. The DPS was calculated for each soil as the ratio of soil test P to the sum of Al and Fe, expressed in moles. A strong relationship exists between oxalate DPS and both Mehlich 1 and Mehlich 3 DPS, suggesting that these tests will be useful for assessing P leaching potential as a function of P saturation in sandy soils."

Summary of Key Findings

Due to limited availability of a traditional soil test required for determining degree of phosphorus saturation (DPS), this research explored alternative soil test methods available for calculating DPS. Soil profiles (over 400 total samples) from sandy soils were analyzed and the DPS was determined for each profile. This research found strong relationships between the traditional DPS test and two alternative tests (Mehlich 1 and Mehlich 3 DPS). From this, in sandy soils these tests will be useful for assessing P leaching as a function of P saturation.

80. ***Walker, L.C., Graetz, D.A., and V.D. Nair, V.D. (2003). Vertical Mobility of Phosphorus from Fertilizer and Manure Sources in Sandy Soils. ASA/SSSA/CSSA Annual Meeting, November 2-6, 2003. Denver, CO. (CD Rom publication).***

Original abstract: "Increased application of manures to cropland and spray fields may result in excessive amounts of phosphorus (P) reaching water bodies unless nutrient

management techniques are practiced. To develop reliable manure management guidelines that are agronomically and environmentally sound, the fate of manure phosphorus should be considered. Vertical transport of P in sandy soils and in tile drained soils may be a source of P to groundwater and surface water, respectively. This column study compared differences in P retention and vertical movement among three P sources (poultry litter, dairy lagoon effluent and triple superphosphate fertilizer) on a low and a heavily manure-impacted soil. In addition, an aluminum water treatment residual (WTR) was used as a soil amendment to evaluate its potential to aid retention of P. The quantity of P leached from the heavily manure-impacted soil was approximately 5-fold higher than from the low manure-impacted soil. Only small differences were observed in the amount of P leached between different P sources. Compared to the non-amended soils, WTR amended soils showed an average reduction in P leached of 21%."

Summary of Key Findings

This research used low and heavily manure-impacted soil columns to compare P retention and vertical movement of various P sources and a soil amendment was used to evaluate potential aid of P retention. Results indicated higher quantity of P leached from heavily manure-impacted soils, the amount of P leached between different sources was small, and amended soils had a higher average reduction in P leached than non-amended soils.

81. **Walker, L.C. (2004). *Vertical Mobility and Dynamics of Phosphorus in Sandy Florida Soils*. M.S. Thesis. Soil and Water Science Department, University of Florida.**

Original abstract: "Animal manures from intensive livestock operations are rich sources of nutrients such as phosphorus (P) which are vital for plant growth. Increased amounts of P in water bodies may lead to unwanted environmental and aesthetic damages to these aquatic ecosystems. Some types of land-applied animal manures may release P even more easily than commercial P fertilizers when in contact with rainwater. The coarse textured sandy soils of Florida are prone to losing P both by surface runoff and leaching down through the soil profile.

A column leaching study was conducted on coarse textured sandy soils with different nutrient management histories (high and low impact by manures) from two commercial dairy farms. Soil columns were treated with three P sources (dairy storage pond effluent, inorganic fertilizer and broiler litter compost), each applied at a rate equivalent to 40 kg P ha⁻¹. The objective of this study was to compare the leaching potential of the three P sources applied to low and highly manure-impacted sandy soils, and also to evaluate the effects of an aluminum based water treatment residual (WTR) on P leaching. Soil columns (25cm L * 7.5 cm I.D.) were leached with simulated rainfall over a 19 week period. Leachate was collected at each leaching event, and at

the end of the study, the soil was sectioned into three depth increments to evaluate the movement of P within the column.

The low manure impacted soil leached overall approximately five times less P than the highly impacted soil. The dairy storage pond effluent treated soils leached P more easily and in greater amounts than the remaining soil treatments. Leachates of dairy storage pond effluent treated soils had higher electrical conductivity (EC) and pH values than the leachates of the remaining treatments.

The Al-WTR reduced the quantities of P leached within P source treatments of the low manure impacted soil by 18-33% and from the high impact soil P source treatments (excluding the control) by 16-22%. It was, however, less effective at reducing the quantities of P leached from dairy effluent treated soil columns when compared to the remaining P sources. The soil columns containing the added Al-WTR had significantly ($P = 0.05$) greater quantities of soil P stored as the stable iron (Fe) and aluminum Al bound P."

Summary of Key Findings

Animal manure is rich in nutrients and is utilized as fertilizer for crop production; however, nitrogen and phosphorus (P) are two major nutrients in manure and are a concern to water quality. The loss of P from land application through leaching or vertical movement through soil profiles is common in sandy soils that have a low P retention capacity. This study evaluated the P leaching characteristics of two soils with low P retention capacity and the effectiveness of water treatment residuals (WTR) for reducing the leaching of P from P treated soils. For this evaluation, a column leaching study using low and high manure-impacted sandy soil columns treated with three P sources were evaluated. Results indicated that different P sources will result in different P release characteristics, even on a short-term basis. In addition, manure type and physical state are critical to a soil's P release characteristics. On a short-term basis, dried manures and those containing mixes of litter or other bedding material leached P less readily from the soil than manures in the liquid or semi-liquid form.

Aluminum WTRs were analyzed in this study and results indicated they had good potential for agricultural use in increasing P sorption capacity of the A horizons of manure fertilized fields. They have a lower heavy metal content than biosolids and are relatively inexpensive, with transportation of them as the only major operating cost. Although they would be useful for soil columns loaded with P from previous management, the ideal use of WTRs is incorporation into soils of new manure application fields.

82. Woodard, K.R, French, E.C., Graetz, D.A., Sollenberger, L.E., Sweat, L.A., Wade, B.L., Rymph, S.J., Macoon, B., Prine, G.M., and Van Horn, H.H. (2000). *Utilization of Dairy Waste Effluent in Year-Round Cropping Systems for Nutrient Recovery and Water*

Quality Enhancement. FDEP 319(h) Contract No. WM714; Final Report. Tallahassee, FL.

Original abstract: Not applicable.

Summary of Key Findings

"Dairy producers are growing forage crops year-round in their waste effluent spray fields to supply feed for dairy animals and prevent effluent minerals from contaminating groundwater. The purpose of this project was to measure the capacity of several forages as well as year-round forage combinations for removing N and P from the soil and preventing them from leaching out of the root zone. Forages within five year-round cropping systems were grown under dairy waste effluent irrigation during three 12-mo cycles. The average annual loading rates of effluent N during the 3-yr period were 508, 697, and 917 kg ha⁻¹. Total forage N removed by the Bermuda grass and rye cropping system (3-yr average) was 465, 528, and 585 kg ha⁻¹ yr⁻¹, respectively for the aforementioned N loading rates. For the corn, forage sorghum, and rye system, N removals were 320, 327, and 378 kg ha⁻¹ yr⁻¹, respectively. During the third 12-mo cycle (1998-1999), N removals by the perennial peanut and rye system were 428, 405, and 503 kg ha⁻¹, respectively, an average increase of 72% over those of the first cycle (1996-1997).

The low removals in the first cycle were related to slow establishment of the perennial peanut which was planted in August, 1995. The higher N removals of the Bermuda grass and rye system were attributed to the combination of high dry matter yield and moderately high intrinsic forage N concentration of the Bermuda grass component. At all loading rates, this system was by far the most effective at preventing nitrate N from leaching out of the root zone. In the corn, forage sorghum, and rye system, high nitrate N concentration peaks in soil solution samples (extracted from 1.5 m below the soil surface using suction cup lysimeters), corresponded to those periods between harvest of one forage and full canopy closure of the next sequentially-planted crop.

Nitrogen removal by the Bermuda grass component of the corn, Bermuda grass, and rye system decreased over the 36-mo period due to reduction in stand. For the perennial peanut component of the corn, perennial peanut, and rye system, N removal increased because stands became more established over the three years. Perennial peanut should not be planted in an active dairy waste effluent spray field because during the establishment period (one to two seasons), excessive leaching will occur.

Annual P removals (3-yr averages) for the Bermuda grass and rye system were 79, 78, and 84 kg ha⁻¹ for effluent P loading rates of 90, 128, and 175 kg ha⁻¹ yr⁻¹, respectively. For the corn, forage sorghum, and rye system, P removals were 60, 54, and 60 kg ha⁻¹

yr⁻¹. Phosphorus removals for the perennial peanut and rye system were inferior to those of the other cropping systems. Phosphorus concentration in soil water samples from lysimeters (0.9 and 1.5 m deep), remained unchanged during the 36-mo period for all cropping systems, with the exception of a 70-d period where levels peaked to extremely high levels in some plots. It was determined that a lagoon additive, which had been poured into the dairy's sediment basins just prior to a waste effluent irrigation, had caused the high P levels."

83. Woodard, K.R., French, E.C., Sweat, L.A., Graetz, D.A., Sollenberger, L.E., Macoon, B., Portier, K.M., Wade, B.L., Rymph, S.J., Prine, G.M., and Van Horn, H.H. (2001). *An Environmental Comparison of Two Year-round Forage Systems Under Dairy Effluent Irrigation in the Suwannee River Area. Pages 49-60 in Proc. 38th Annual Florida Dairy Production Conference, University of Florida, Gainesville.*

Original abstract: "Concentrated sources of dairy manure represent significant water pollution potential. The southern United States may be more vulnerable to water quality problems than some other regions because of climate, typical farm size, and cropping practices. Dairy manure can be an effective source of plant nutrients and large quantities of nutrients can be recycled through forage production, especially when multi-cropping systems are utilized. Linking forage production with manure utilization is an environmentally sound approach for addressing both of these problems. Review of two triple-crop systems revealed greater N and P recoveries for a corn silage-Bermuda grass hay-rye haylage system, whereas forage yields and quality were greater for a corn silage-corn silage-rye haylage system, when manure was applied at rates to supply N. Nutrient uptake was lower than application during the autumn-winter period, and Bermuda grass utilized more of the remaining excess than a second crop of corn silage. Economic comparison of these systems suggests that the added value of the two corn silage crop system was not enough to off-set its increased production cost. Therefore, the system that included Bermuda grass demonstrated both environmental and economic advantages. Review of the N and P uptake and calculated crop value of various single, double, and triple crop forage systems indicated that the per hectare economic value as well as the N and P uptakes tended to follow DM yields, and grasses tended to out-perform broadleaf forages. Taken across all systems, systems that included Bermuda grass tended to have some of the highest economic values and uptakes of N and P. Manure applied at rates to supply N results in application of excess P, and production will not supply adequate quantities of forage to meet the herd's needs.

Systems that lower manure application and supply supplemental N to produce all necessary forage under manure application will likely be less economically attractive due to additional costs of moving manure further and applying it to greater land areas, but will be environmentally necessary in most cases. Intensive forage systems can produce acceptable to high quality forage, protect the environment, and be

economically attractive. The optimal manure-forage system will depend on the farm characteristics and specific local conditions. Buffers and nutrient sinks can protect streams and water bodies from migrating nutrients and should be included as a part of crop production systems.”

Summary of Key Findings

The purpose of this study 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 in a dairy effluent spray field in the Suwannee River watershed. The authors’ objectives were to 1) 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 2) identify periods within a cropping cycle that are particularly vulnerable to nitrate-N leaching and determine causal factors.

The report analyzed the Bermuda grass-rye system (BR) against the corn-forage sorghum-rye system (CSR) and found the BR system to be superior. Nitrogen removal for the BR system exceeded that of the CSR in all four 12-month cycles. For rye, the cool-season component, dry matter yield, forage N percentage and N removal did not differ between systems. Therefore the differences in N removal between the BR and CSR systems were attributable to the performance of warm-season components. Bermuda grass 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.

The ideal crop for long term N removal in dairy spray fields has a higher forage N percentage, produces high yields, 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, Bermuda grass 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. The corn plus forage sorghum combination produced stable yields over the 4-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, considering the portion of a 12-month cycle taken up by this forage (about 100 days).

The BR system was also superior to CSR at preventing nitrate-N from leaching below the primary rooting zone. The average nitrate-N concentrations for the BR systems did not exceed 20 mg/L, whereas in the CSR system, the nitrate-N concentrations reached more than 60 mg/L. 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.

The BR system consists of a highly productive perennial sod that was harvested several times during the warm-growing season. The Bermuda grass 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 Bermuda grass were much shorter than the transition periods between annual crops.

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. The authors submit that the Bermuda grass 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 Bermuda grass harvest.

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. 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, resulting in high nitrate-N peak concentrations during the early growth of rye. The authors stipulate that 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 buildup in the topsoil was low because lower temperatures reduced the rate of conversion from effluent-N to nitrate-N.

These findings suggest that year-round forage systems which include a perennial warm-season grass, such as Bermuda grass, are better than those made up entirely of annual forages, such as the corn plus sorghum combination, at preventing nitrate-N loss to groundwater in dairy effluent spray fields.

84. **Woodard, K.R., French, E.C., Sollenberger, L.E., Graetz, D.A., Prine, G.M., Macoon, B., Sweat, L.A. (2002). *Best Management Practices for Nitrogen Fertilization of High Quality Forage Grass in the Middle Suwannee River Area. Final Report for the Florida Department of Agriculture and Consumer Services. Gainesville, Florida.***

Original abstract: Not applicable.

Summary of Key Findings

"The Middle Suwannee River Basin (MSRB) in North Florida is an environmentally sensitive area because of its deep, sandy soils and underlying 'unconfined' hydrogeology. Over the last decade, elevated and increasing nitrate levels have been

measured in the Suwannee River as well as in the Upper Floridan Aquifer underlying the MSRB. The numerous agricultural operations in the region have been identified as possible nitrate sources.

The purpose of this project was to evaluate different N sources and rates for bermudagrass hay production in the MSRB, taking into account the risk of groundwater contamination as well as forage yield and nutritive value. Our ultimate goal was to determine BMPs for N fertilization to be recommended to hay producers. The study was conducted at two locations including the North Florida Research and Education Center - Suwannee Valley site (SV) near Live Oak and the Townsend site near Bell, Florida. Soils are deep, sandy Entisols (Typic Quartzipsamments, thermic). The bermudagrass 'Tifton 85' (*Cynodon* spp.) was planted at each site in the spring of 1998. Treatments were initiated in July 1998, midway through the 1998 growing season. Treatments were sole N source ammonium nitrate (AMN) applied at N rates of 37, 75, 112, and 150 lb/acre per growth period (harvest interval). Sole N source broiler litter (BL) was applied at N rates of 75 and 112 lb/acre. A combination N source consisting of ammonium nitrate and broiler litter (AMN-BL) was applied at N rates of 75 and 112 lb/acre where each source supplied half of the N. All N sources were surface applied.

The growing season for bermudagrass in the MSRB is from April to October. The bermudagrass received fertilization treatments during two growth periods in the latter half of the 1998 growing season, four growth periods during the 1999 season, and three periods during the 2000 season. At the end of each growth period, the bermudagrass was harvested and dry matter yield, forage N concentration, and N removal were measured. To monitor nitrate N ($\text{NO}_3\text{--N}$) concentration in soil water below the primary rooting zone, two suction-cup lysimeters were installed per plot. Suction cups were 4.7 feet below the soil surface. Lysimeters were sampled at 14-day intervals from July 1998 to March 2001. Dry matter yield, forage N concentration, and N removal increased to the highest N rate for AMN. Dry matter yield increased less per unit of N applied at the higher N rates. In contrast, forage N concentration increased at least as much per unit of N applied at the high as the low N rates. Nitrogen removal increased at a near constant rate as N rate increased. Though a certain degree of interpolation of leaching data was required, the study supports the University of Florida, Institute of Food and Agricultural Sciences recommended N rate of 80 lb/acre per growth period (inorganic N sources). Nitrate N concentration ($\text{NO}_3\text{--N}$) in soil water below the primary rooting zone was minimal when AMN was applied at the 75 N rate. It is unlikely that $\text{NO}_3\text{--N}$ concentrations in groundwater emanating directly from bermudagrass hayfields where the 80 lb/acre N rate is being applied, will exceed the groundwater standard of 10 mg/L, provided the bermudagrass is fully established. Results also lend support to the interim BMP for the maximum N rate of 100 lb/acre per growth period, that was

adopted for hay production in the Suwannee River Water Management District (SRWMD) by the Florida Department of Agriculture and Consumer Services. Nitrate N leaching patterns for the N rate of 112 lb/acre were marginally acceptable during the 1999-00 and 2000-01 cycles. During these two cycles, the bermudagrass was fully established.

Dry matter yield and N removal were substantially lower for BL than AMN while AMNBL was intermediate. Forage N concentration was generally lower for BL compared to AMN. Nitrate N concentration in soil water below the rooting zone did not differ between AMN, BL, and AMN-BL at the 75 N rate. At the 112 N rate, concentrations were ranked: AMN > AMN-BL > BL. Soil water NO₃--N concentration was very low throughout the study in plots receiving BL.

Plant removal of residual N measured in July 2001 was negligible for all sources (last fertilizer application occurred in August 2000). Results suggest that a considerable portion of the N in the surface-applied broiler litter was volatilized into the atmosphere. With AMN, as N rate increased from 37 to 150 lb/acre, weed ratings for both broadleaf and Bahia grass (lower rating indicates fewer weeds) decreased at a linear rate. At times, there were more weeds in plots receiving BL than AMN.

However, weed ratings for plots receiving

AMN at the 37 N rate were > those for plots receiving BL. It is likely that the amount of available N for bermudagrass growth is inversely related to the severity of weed problems. With more N available, bermudagrass growth will be more aggressive resulting in greater suppression of weeds.

We concluded that the 'deep stacked' broiler litter used in the study was not a source of viable weed seeds and that the higher weed ratings occasionally observed in plots receiving BL resulted from the less aggressive growth of the bermudagrass, thus allowing more opportunity for weeds to emerge and grow."

85. Woodard, K.R., French, E.C., Sweat, L.A., Graetz, D.A., Sollenberger, L.E., Macoon, B., Portier, K.M., Wade, B.L., Rymph, S.J., Prine, G.M., and Van Horn, H.H. (2002). *Nitrogen Removal and Nitrate Leaching for Forage Systems Receiving Dairy Effluent*. *J. Environ. Qual.* 31 : 1980 - 1992.

Original abstract: "Florida dairies need year-round forage systems that prevent loss of N to ground water from waste effluent spray fields. Our purpose was to quantify forage N removal and monitor nitrate N (NO₃ -N) concentrations in soil water below the rooting zone for two forage systems during four 12-mo cycles (1996-2000). Soil in the spray field is an excessively drained Kershaw sand (thermic, uncoated Typic Quartzipsamment). Over four cycles, average loading rates of effluent N were 500, 690, and 910 kg ha⁻¹ per cycle. Nitrogen removed by the Bermuda grass (*Cynodon* sp.)-rye (*Secale cereale* L.) system (BR) during the first three cycles was 465 kg ha⁻¹ per cycle

for the low loading rate, 528 kg ha⁻¹ for the medium rate, and 585 kg ha⁻¹ for the high. For the corn (*Zea mays* L.)-forage sorghum [*Sorghum bicolor* (L.) Moench]-rye system (CSR), N removals were 320 kg ha⁻¹ per cycle for the low rate, 327 kg ha⁻¹ for the medium, and 378 kg ha⁻¹ for the high. The higher N removals for BR were attributed to higher N concentration in Bermuda grass (18.1–24.2 g kg⁻¹) than in corn and forage sorghum (10.3–14.7 g kg⁻¹). Dry matter yield declined in the fourth cycle for Bermuda grass but N removal continued to be higher for BR than CSR. The BR system was much more effective at preventing NO₃⁻-N leaching. For CSR, NO₃⁻-N levels in soil water (1.5 m below surface) increased steeply during the period between the harvest of one forage and canopy closure of the next. Overall, the BR system was better than CSR at removing N from the soil and maintaining low NO₃⁻-N concentrations below the rooting zone.”

Summary of Key Findings

Most of the dairies in northern Florida are involved in the year-round production of forage crops in manure effluent spray fields. In the present study, five year-round forage systems were evaluated under dairy effluent irrigation over four 12-month cycles and with three loading rates of effluent N. Results are analyzed in this report from two of the forage systems, Bermuda grass-rye (BR) where Bermuda grass represents a perennial sod component, and corn-forage sorghum-rye (CSR) where all three crops are annuals.

The authors’ objectives were to 1) 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 2) identify periods within a 12-month cropping cycle that are particularly prone to NO₃⁻-N leaching and determine causal factors.

The N analysis involved a modification of the standard Kjeldahl procedure followed by automated colorimetry with a Technicon Auto Analyzer. Responses were evaluated by fitting mixed effects models with the PROC MIXED procedure of SAS. To determine the nature of the effect of effluent N loading rate on forage responses (N removal, dry matter [DM] yield and forage N concentration), contrasts for linear and quadratic effects were examined. To compare soil water NO₃⁻-N concentration means among loading rates for each sampling date within each forage system and 12-month cycle, a paired comparison of least squares means was made with pooled variances from the entire project. A predecided 0.10 significant level was chosen for treatment and interaction terms.

The main effect of forage system was significant for DM yield, N concentration, and N removal whereas the effect of effluent N loading rate was significant for N

concentration and N removal but not for DM yield. The cycle effect was significant for all three response parameters.

The ideal forage for N removal in dairy effluent spray fields would produce high yields, have a high forage N concentration, consume N with increasing loading rate, and maintain a high level of crop performance over several years. Of the four components in the two systems, Bermuda grass was closest to possessing these attributes. Over the first three 12-month cycles, it produced high yields and had moderately high N concentration, which increased significantly with loading rate. A shortcoming was its decline in yield in the fourth cycle due to the reduction in stand that occurred mainly in plots receiving the higher N rates. The performance of the rye component in DM yield, N concentration and N removal did not differ between systems; therefore the effectiveness of the systems was determined by the performance of warm-season components. The corn plus sorghum combination produced stable yields over the 4-year period, but its major shortcoming was low N concentration. Thus, due to its relatively stable and substantially higher N concentrations, the BR system was found to be superior in N removal.

The BR system was also superior to CSR at preventing NO_3^- -N from leaching below the primary rooting zone. Growth phases of the annual forages in CSR had a much greater influence on leaching patterns than those of the BR system. In CSR, the period between harvest of one forage and canopy closure of the next was identified as being highly prone to NO_3^- -N leaching due to the time required for seedling emergence and development. During this period N uptake, as well as water usage, are at high levels. The BR system 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, thus limiting the opportunity for buildup and major leaching events to occur. Therefore, the authors propose that year-round forage systems which include a productive, perennial grass (such as Bermuda grass) are better than those made up entirely of annual forages at preventing NO_3^- -N loss to groundwater.

86. Woodard, K.R., French, E.C., Sweat, L.A., Graetz, D.A., Sollenberger, L.E., Macoon, B., Portier, K.M., Wade, B.L., Rymph, S.J., Prine, G.M., and Van Horn, H.H. (2003). *Nitrogen Removal and Nitrate Leaching for Two Perennial, Sod-Based Forage Systems Receiving Dairy Effluent Forage Systems*. *J. Environ. Qual.* 32(3) : 996 - 1007.

Original abstract: "In northern Florida, year-round forage systems are used in dairy effluent spray fields to reduce nitrate leaching. Our purpose was to quantify forage N removal and monitor nitrate N (NO_3^- -N) concentration below the rooting zone for two perennial, sod-based, triple-cropping systems over four 12-mo cycles (1996–2000). The soil is an excessively drained Kershaw sand (thermic, uncoated Typic Quartzipsamment). Effluent N rates were 500, 690, and 910 kg ha⁻¹ per cycle. Differences in N removal between a corn (*Zea mays* L.)–Bermuda grass (*Cynodon* spp.)–rye (*Secale*

cereale L.) system (CBR) and corn– perennial peanut (*Arachis glabrata* Benth.)–rye system (CPR) were primarily related to the performance of the perennial forages. Nitrogen removal of corn ($125\text{--}170\text{ kg ha}^{-1}$) and rye ($62\text{--}90\text{ kg ha}^{-1}$) was relatively stable between systems and among cycles. The greatest N removal was measured for CBR in the first cycle (408 kg ha^{-1}), with the Bermuda grass removing an average of 191 kg N ha^{-1} . In later cycles, N removal for Bermuda grass declined because dry matter (DM) yield declined. Yield and N removal of perennial peanut increased over the four cycles. Nitrate N concentrations below the rooting zone were lower for CBR than CPR in the first two cycles, but differences were inconsistent in the latter two. The CBR system maintained low NO_3^- -N leaching in the first cycle when the Bermuda grass was the most productive; however, it was not a sustainable system for long-term prevention of NO_3^- -N leaching due to declining Bermuda grass yield in subsequent cycles. For CPR, effluent N rates $\geq 500\text{ kg ha}^{-1}\text{ yr}^{-1}$ have the potential to negatively affect ground water quality.”

Summary of Key Findings

In the present study, five year-round forage systems were evaluated under dairy effluent irrigation over four consecutive 12-month cycles and with three loading rates of effluent N. Results are reported from two of the forage systems, corn-Bermuda grass-rye (CBR) and corn-perennial peanut-rye (CPR). The authors’ objectives were to measure the capacities of the year-round forage systems and system components to remove N from the soil and prevent NO_3^- -N from leaching below the rooting zone.

The N analysis involved a modification of the standard Kjeldahl procedure followed by automated colorimetry with a Technicon Auto Analyzer. Responses were evaluated by fitting mixed effects models with the PROC MIXED procedure of SAS. To determine the nature of the effect of effluent N loading rate on forage responses (N removal, dry matter [DM] yield and forage N concentration), contrasts for linear and quadratic effects were examined. To compare soil water NO_3^- -N concentration means among loading rates for each sampling date within each forage system and 12-month cycle, a paired comparison of least squares means was made with pooled variances from the entire project. A predecided 0.10 significant level was chosen for treatment and interaction terms.

The main effect of forage system was significant for dry matter (DM) yield, N concentration, and N removal whereas the effect of effluent N rate was significant for N concentration and N removal but not for DM yield. The cycle effect was significant for DM yield and N concentration but not for N removal.

The authors concluded that the forage system has little influence on dry matter yield, forage N concentration and N removal of the annual forage components (corn and rye). Differences between the CBR and CPR systems were mainly due to the perennial species. Nitrogen removal was generally greater for CBR because of superior yields

along with N concentrations that were greater than or equal to those of CPR. Similarly, the Bermuda grass in CBR removed much more N from the soil than the perennial peanut in CPR. In subsequent cycles, the Bermuda grass became progressively slower to recover following corn harvest and its yield and N removal declined. This indicates that the type of Bermuda grass used (Tifton 85) was moderately intolerant of the CBR system, especially at the higher effluent N rates. Conversely, perennial peanut was very tolerant of the CPR system at all loading rates as demonstrated by increasing yield during the 4-year project, though the N concentration remained relatively stable. Therefore, the increase in N removal was mainly the result of an increase in yield and not N concentration.

Leaching patterns of the CBR system were consistent with the decline in performance of the Bermuda grass. The lowest $\text{NO}_3\text{-N}$ concentrations in soil water below the rooting zone occurred in the first cycle, but as Bermuda grass yield declined in subsequent cycles, $\text{NO}_3\text{-N}$ levels increased. Thus, CBR was not a sustainable forage rotation for long-term control of nitrate leaching due to the decline in Bermuda grass performance. Although yield and N removal increased over the four cycles for perennial peanut in CPR, consistent changes in leaching patterns were far less discernable. The CBR system maintained significantly lower $\text{NO}_3\text{-N}$ concentrations than CPR in the first two cycles at all loading rates, but differences between systems in the last two cycles were not consistent. The leaching patterns of CPR indicate that its use in dairy spray fields, with effluent N rates greater than or equal to 500 kg ha^{-1} gas a high risk of negatively affecting ground water quality.

To control leaching year-round in dairy effluent spray fields, forage selection should match seasonal changes in the nitrate load in the topsoil and not the constant loading of effluent N to the soil surface.

87. Woodard, K.R., French, E.C., Sollenberger, L.E., Sweat, L.A., Rymph, S.J., Nair, V.D., Graetz, D.A., Van Horn, H.H, and Joo, J. (2003). *Degree of Phosphorous Saturation and Leaching Potential in Soils of the Middle Suwannee River Area Under Varying Application Rates of Dairy Effluent and Cropping Systems*. FDEP 319(h) Contract No. WM740; Final Report. Tallahassee, Florida.

Original abstract: Not applicable.

Summary of Key Findings

" The number of dairy cows have steadily increased over the last two decades in basins surrounding the Reach 3 segment of the Suwannee River. This area is generally referred to as the Middle Suwannee River Basin (MSRB). Dairies in the MSRB have been identified as a potential source of increasing nitrate levels in ground water entering Reach 3 from the Upper Floridan Aquifer (UFA). However, phosphorus (P) from dairy operations has posed less of an environmental threat to ground water

quality. Generally, for plant nutrients in surface-applied dairy manure to reach the Suwannee River, they must leach through a soil profile made up of deep sands, then pass through underlying thin, unconfined (often karst) geological layers before reaching the surface of the Upper Floridan Aquifer. From there, the nutrients (contaminates) move laterally with the flow of UFA waters toward the Suwannee River. It is common for the saturated zone to be 30 to 60 feet below the land surface in the MSRB. Nitrate is easily leached from the sandy upland soils that are common to the region, while P is normally considered to be far less mobile. The capacity of a soil to retain P is generally associated with amounts of aluminum (Al) and iron (Fe) that are present. The primary objective of the project was to determine the retention capacity of P in surface and subsurface soil layers/horizons within four dairy effluent sprayfields and nearby unimpacted sites in the Suwannee River area, by measuring the degree of phosphorus saturation (DPS). In addition, the current 3-year project made it possible to continue a previous 3-year project, where five year-round forage systems were being evaluated for phosphorus recovery in a spray field at North Florida Holsteins dairy (NFH) near Bell. The forage systems included bermudagrass-rye (BR), perennial peanut-rye (PR), corn-forage sorghum-rye (CSR), corn-Bermuda grass-rye (CBR), and corn-perennial peanut-rye (CPR). Average dairy effluent loading rates of P at NFH were 70, 105, and 150 lb/acre per 12-month cycle. Estimates for DPS were above 60% in topsoils of the four dairy effluent sprayfields during 2000 and 2001. Values declined with soil depth at all spray field sites. At the NFH spray field, DPS estimates decreased sharply from the topsoil to the underlying subsoil layer to a 20" depth (range 29-43%). From there, DPS declined gradually. The DPS range was from 10 to 19% at a soil depth of 38-48". During the first two 12-month cycles at NFH, the BR system recovered the greatest amount of P (avg. 81 lb/acre per cycle) while the PR and CPR systems recovered the least. Over the next three 12-month cycles, however, P removal declined for BR because bermudagrass (Tifton 85) yield declined. The 5-cycle average P removal for BR was 60 lb/acre. For the CSR and CBR systems, average P removal was 47 and 48 lb/acre per cycle, respectively. The CPR and PR systems averaged 38 and 40 lb/acre, respectively. For Tifton 85 bermudagrass in CBR, substantial reductions in stand and yield occurred in later cycles. The perennial peanut Florigrade in PR and CPR was slow to establish and had low P removal, a result of low yield and low to moderate forage P concentration. The dry biomass tonnage of the forage systems was unaffected by effluent P loading rate. Forage P concentration of warm-season components declined marginally with an increase in loading rate. For rye, the winter component of all systems, there was a slight increase in forage P concentration with higher loading rates. Phosphorus removal of the forage systems was unaffected by effluent P loading rate. At the NFH spray field, a significant increase in P concentration in soil water from five feet below the soil surface (from suction lysimeters sampled at 14-day intervals), occurred during the second quarter of the fifth cycle (July-September, 2000). The average P concentration for the quarter was 0.6 mg/L. Phosphorus concentration did not exceed 0.1 mg/L for all other quarters except for the third and fourth quarters (October-March) of the 1997-

98 cycle. On October 22, 1997, a bacterial lagoon product was added to the effluent sediment separation basin just hours before the project spray field received an overall effluent application. Over a 70-day period that began in mid-November 1997, P concentration in soil water from 3 and 5 feet below the soil surface increased to extremely high values in several plots, then fell rapidly to low concentrations similar to those measured before the October 22 effluent application. Results of the project suggest that to evaluate the potential risk of P contamination of ground water from dairy effluent sprayfields within the MSRB, the capacity of the entire soil profile to retain P should be considered. Also, the bermudagrass-rye system had the greatest capability for recovering P from spray field soils, an outcome directly related to the high yielding potential and moderately high forage P concentration of full-season bermudagrass. Bermudagrass Tifton 85 was not recommended for the CBR system. The perennial peanut Florigraze was not recommended for P recovery in dairy sprayfields, regardless of forage system."

88. Woodard, K.R., Sollenberger, L.E., Graetz, D.A., Chambliss, C.G., and Scholberg, J.M. (2006). *Verification of Interim BMPs for Nitrogen Fertilization of Hayfields within the Suwannee River Water Management District. Final Report Florida Department of Agriculture and Consumer Service, Tallahassee, Florida.*

Original abstract: Not Applicable.

Summary of Key Findings

"In the Lower Suwannee River Basin (LSRB), elevated nitrate concentrations in groundwater have been linked to agricultural production activities. Bermudagrass [*Cynodon dactylon* (L.) Pers.] hay production is a major industry that provides forage for numerous dairy and beef cattle (cow-calf) operations in the basin. Our objective was to determine the environmental impact of applying 100 lb/acre of fertilizer N per growth interval of 'Coastal' bermudagrass, the most commonly grown cultivar for hay production in the LSRB. This N rate was the maximum quantity allowed by an interim measure adopted for hay production in the region by the Florida Department of Agriculture and Consumer Services (FDACS) in 2000. Three 10-acre Coastal bermudagrass hayfields located in northwest Gilchrist County were selected for the project. Within each hayfield, ten suction lysimeters were installed to collect soil water from below the rooting zone (5-ft depth). Also, five wells were installed to monitor nitrate-N levels within the upper water table which ranged from 33 to 44 feet in depth. The hayfields were harvested three times during each of the 2003, 2004, and 2005 warm-growing seasons. Soil water and well water were sampled at 14- and 21-day intervals, respectively, from April 2003 to March 2006. Each hayfield was fertilized with a different fertilizer N source. The designated 'tobacco barn' hayfield (TBL) received a liquid N source (21% N). The granular N source, ammonium nitrate, was applied to the 'highway' hayfield (HWG). Both hayfields were fertilized with the 100lb/acre N rate per growth period. The 'home place' hayfield (HPAG) was fertilized

in the spring with anhydrous ammonia at a N rate of 125 lb/acre. This quantity of N was considered to be a 100-lb equivalent rate, allowing for 20% loss of N via surface volatilization. A target N rate of 100 lb/acre was applied at the beginning of each of the second and third growth periods at HPAG, using ammonium nitrate.

The 3-year average dry matter (DM) yield was 4.6, 5.0, and 6.2 ton/acre for the HPAG, HWG, and TBL hayfields, respectively. Corresponding average hay yield (12% moisture) was 5.2, 5.7, and 7.0 ton/acre, respectively. Forage N concentration ranged from 1.3 to 1.7% DM. The average annual quantity of N removed in the hay ranged from 145 to 171 lb/acre. Apparent N recovery ranged from 48 to 54% during the 3-year period. The lowest nitrate-N concentration in soil water below the rooting zone was recorded at TBL. From April 2003 to March 2006, there were only two sampling dates where nitrate-N levels exceeded 10 mg/L. The highest peak concentration was near 20 mg/L. At HWG, there were two concentration peaks that exceeded 40 mg/L and one that was near 20 mg/L. At HPAG, there were three major peaks, one exceeding 30 mg/L and two near 20 mg/L. There was no obvious relationship between nitrate-N leaching patterns in soil water and the relatively constant nitrate levels found in well water over the 3-year project. Nitrate-N concentration in well water ranged from 3 to 6 mg/L in all hayfields. The relatively few concentration peaks observed in soil water occurred mostly over short time periods, indicating that the moisture fronts leaving the rooting zone were narrow in thickness. We suggest that as these nitrate-concentrated moisture fronts moved downward toward the water table, they became more diffuse and merged with less concentrated fronts, which caused their effects on well water concentration to be diminished. Based on well water nitrate-N concentration measured over three years, the environmental impact of the 100-lb N rate per growth interval was within acceptable limits of Florida's groundwater standard."