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NITROGEN CONCENTRATIONS IN AGRICULTURAL DRAINAGE WATER IN SOUTH FLORIDA

L. T. Capone, F. T. Izuno, A. B. Bottcher, C. A. Sanchez, F. J. Coale, D. B. Jones

ABSTRACT. *The eutrophic state of Lake Okeechobee and the potential degradation of the Water Conservation Areas (WCAs) and Everglades National Park (ENP) are primary environmental concerns in south Florida. Drainage water in the Everglades Agricultural Area (EAA) is alleged to be contributing to the accelerated eutrophication of Lake Okeechobee and the undesirable vegetative changes in the WCAs and the ENP.*

Although south Florida's water issues are focused primarily on phosphorus (P), the role of nitrogen (N) in agricultural (i.e., N:P ratios) drainage water leaving the EAA and its effects on the environment has also been questioned.

*Baseline total nitrogen (TN), total dissolved Kjeldahl nitrogen (TDKN), nitrate (NO_3^-), and ammonium (NH_4^+) concentrations in drainage water for various crop and field conditions in the EAA were determined. Thirty-six 0.7 ha plots were installed at four sites. Average TN, TDKN, NO_3^-, and NH_4^+ concentrations were determined for each of five farm practices: 1) Sugarcane (*Saccharum spp.*) production; 2) radish production (*Raphanus sativus L.*); 3) cabbage (*Brassica oleracea L.*) production; 4) flooded fallow fields; and 5) drained fallow fields. Baseline TN and TDKN concentration data for main farm canals and rainfall were also collected.*

Average TN concentrations ranged from a low of 1.83 mg L^{-1} for radish plots during drainage events to a high of 77.04 mg L^{-1} during the drain-down of flooded fallow rotation plots. Drainage water TN and TDKN concentrations peaked during the first substantial rainfall following a prolonged period of low rainfall. Nitrate concentrations ranged from 9 to 32% of TN. Main farm canal and rainfall TN concentrations averaged 5.08 and 1.27 mg L^{-1}, respectively.

Total nitrogen in drainage water leaving the fields during the 1989 calendar year ranged from 8.89 to 50.54 kg ha^{-1}. The farm practice with the lowest TN loading rate was sugarcane (8.89 kg ha^{-1}) and that with the highest (50.5 kg ha^{-1}) was flooded fallow fields following radishes. Flooded fallow fields following radishes yielded a TN loading rate of 50.5 kg ha^{-1}. Total nitrogen loading to the fields from rainfall averaged 12.73 kg ha^{-1}.

Keywords. *Nitrogen, Eutrophication, Drainage, South Florida, Best management practices, Everglades agricultural area, Fertilization, Water quality, Mineralization.*

The Everglades Agricultural Area (EAA) in south Florida is a 280 000-ha tract of land located between Lake Okeechobee to the north, and the Water Conservation Areas (WCAs) and the Everglades National Park (ENP) to the south (fig. 1). The soils of the EAA are predominantly histosols, ranging in depth from about 0.30 to 3 m (adjusted for soil subsidence at a rate of approximately 2.5 cm yr^{-1}), underlain by marl and limestone (Snyder et al., 1978). Approximately 200 000 ha are cultivated for production of primarily sugarcane (*Saccharum* spp.), vegetables, rice (*Oriza sativa* L.), and sod.

On-farm water management in the EAA is accomplished by using open ditches to raise (irrigate) or lower (drain) the water table. Low head, large volume, axial flow, pump stations are situated at the head of the main farm canals to discharge water off-farm into the area canal network. Irrigation water can be brought into the farms through

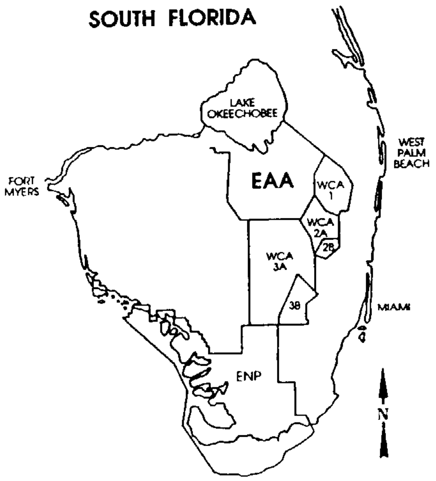

Figure 1–Layout of the Lake Okeechobee-EAA-WCA-ENP water management system.

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culverts, gate structures, or by back siphoning through the pump barrels.

In recent years, the EAA has come under scrutiny by environmental, agricultural, and government water management and regulatory groups who are concerned with the potentially adverse environmental effects of nutrient-rich waters leaving the agricultural lands during drainage. Historically, agricultural drainage water had been pumped northward into Lake Okeechobee, southward into the WCAs and ENP, or out to the east and west coasts of the Florida Peninsula. The nutrient-enriched agricultural drainage water may be contributing to the eutrophic status of Lake Okeechobee and the alteration of plant communities in the WCAs (LOTAC I, 1986; LOTAC II, 1989). Preservation of the natural state of the ENP and the estuaries through which drainage water is discharged to the ocean are additional concerns (LOTAC II, 1989; SFWMD, 1990).

Two potential causes for the reported environmental changes in Lake Okeechobee and the WCAs are: 1) the disruption of natural hydroperiods in Lake Okeechobee and the WCAs due to their use as water storage sites; and 2) the increased influx of nutrients from drainage of adjacent agricultural lands (LOTAC II, 1989).

The histosols of the EAA formed under eutrophic conditions such that the rate of photosynthesis exceeded respiration and, therefore, biological materials accumulated faster than they decomposed. When the EAA histosols were drained, oxidation reversed centuries of organic matter accumulation. Drainage created aerobic conditions and rapid microbial nitrogen (N) mineralization resulted in N enrichment of drainage water.

Some reports suggest that Lake Okeechobee is phosphorus (P) limited (LOTAC II, 1989) while others suggest it is N limited (Brezonik et al., 1979). These differing views may reflect different testing methods, differences in analyses, or temporal trends in the area.

Brezonik et al. (1979) stated that inorganic N:P ratios suggest N limitation while total N:P ratios indicate P limitation. Morris (1975) reported that backpumped water N:P ratios were nearly equal to rainfall N:P ratios, and therefore, neither element is limiting. Federico et al. (1981) reported that Lake Okeechobee is shifting from a nutrient balanced condition, with both elements limiting on occasion. The balance tended towards potential N limitation but they stressed that this possible shift is unstable. They based this hypothesis on the decrease in the annual inorganic N:P ratios observed during their seven-year study period. Brezonik et al. (1979) asserted that internal loading of inorganic N from the sediments prevents N limitation in all but the northern areas of Lake Okeechobee. However, they also suggest a seasonal trend in nutrient limitation in the southern end of the lake due to backpumping.

In other words, when backpumping occurs, the southern end of the lake is P limited. During the dry periods, the southern rim area may be N limited. Apparently, this was not justification enough to control N rather than P in Lake Okeechobee (Federico et al., 1981).

Nitrogen concentrations in the Lake Okeechobee-EAA-WCA-ENP system have been monitored for years (SFWMD, 1986). However, the monitoring programs have concentrated primarily in Lake Okeechobee and at discharge points leaving the EAA to the north and south. Very little water quality monitoring has been done at the farm level within the EAA.

Lake-wide nitrogen levels have decreased since 1980 and continue to fluctuate, but have become relatively stable in recent years (LOTAC II, 1989). However, trends in nitrogen are difficult to predict due to the complex nature of the nitrogen cycle. Backpumping of drainage waters from the EAA has had a variable impact on N levels, depending on rainfall patterns and water management practices. Thus in 1969, backpumping accounted for only 10% of the total N load to Lake Okeechobee, but in 1973 to 1974 it represented 27 to 32% of the loads (Brezonik et al., 1979).

Mean annual total nitrogen (TN) concentrations in Lake Okeechobee ranged from 1.63 to 2.62 mg L^{-1} (SFWMD, 1988). The mean annual TN concentrations of drainage water pumped into Lake Okeechobee from the EAA ranged from 2.56 to 5.82 mg L^{-1} between 1973 and 1979 (SFWMD, 1988). During 1983 to 1985, mean annual TN concentrations of drainage water pumped into Lake Okeechobee, measured at the same locations, ranged from 2.72 to 8.10 mg L^{-1} (SFWMD, 1988). The TN concentrations for 1985 to 1986 measured at the same locations, ranged from 2.08 to 7.22 mg L^{-1}.

Mean annual TN concentrations for drainage water entering the WCAs from the EAA through four pump stations ranged from 2.15 to 5.83 mg L^{-1} between 1978 and 1986 (LOTAC II, 1989). Total nitrogen concentrations in the interior of the WCAs ranged from 2.15 to 3.05 mg L^{-1} between 1978 and 1982 (Swift and Nicholas, 1985).

A study by CH2M-Hill (1978) compared the mean TN concentrations in drainage water from a sugarcane plantation, vegetable farm, and cattle ranch in the EAA. Concentrations did not show differences between the three sites.

Total nitrogen concentrations in bulk precipitation (defined as rainfall plus dry fallout) collected at a major pump station in the EAA averaged 2.10 mg L^{-1} between 1972 and 1974 (Waller and Earle, 1975). At a second pump station, the average bulk precipitation TN concentration was 1.16 mg L^{-1} between April 1976 and March 1977 (CH2M-Hill, 1978). Bulk precipitation TN concentrations have been shown to range between 0.57 and 1.01 mg L^{-1} at three geographically separate sites (CH2M-Hill, 1978).

Nitrogen loadings vary, depending greatly on the soil-type and land use. A study by CH2M-Hill (1978) shows definite seasonal trends for nitrogen in backpumped water, with peak TN loads occurring in August and September (i.e., the peak rainfall periods when extended pumping occurs). Total nitrogen loads were lower in the winter and early spring when pumping periods were generally short and soil temperatures were lower. Lower soil temperatures limit the soil mineralization process as discussed in detail by Messer and Brezonik (1977).

Basin-scale water managers and the agricultural industry in the EAA have been mandated to reduce nutrient loads (specifically phosphorus) from agricultural lands (United States District Court, 1991; Florida State House of Representatives, 1991). Reductions in P could cause a shift in the N:P ratios further complicating the clean up efforts. In doing so, managers are also faced with the restriction that runoff volumes from agricultural lands, which are necessary to maintain the area water supply, must not decrease significantly (no more than 20%). Hence, reduced N loading must occur from reductions in N concentrations as well as from retaining farm drainage water on the farm retention. One proposed method of reducing N concentrations in drainage water leaving the EAA is to develop and implement agricultural "best management practices" (BMPs).

OBJECTIVES

The primary objective of this study was to establish the current TN, NH_4^+ and NO_3^- concentrations in drainage water from sugarcane, vegetable, drained fallow, and flooded fallow fields in the EAA. Secondary objectives were to measure bulk precipitation TN concentrations, and TN, NO_3^-, and NH_4^+ concentrations at main farm pump stations within the EAA. The establishment of present background N concentrations and loadings is vital because when currently mandated P reduction BMPs are installed to reduce P, N will also be affected.

MATERIALS AND METHODS

Four sites were selected to monitor drainage water N concentrations in existing fields in the EAA. Each site consisted of eight or twelve 0.7-ha plots typically arranged as shown in figure 2. Each plot included the plot ditch and half the land area on both sides of the plot ditch. The dashed lines in figure 2 represent theoretical hydraulic boundaries. The ditches were at the same elevation throughout each site. The areas within the dashed lines drained to the enclosed plot ditch (fig. 2). To reduce the potential of nonuniform overland flow to the plot ditches, the plots were laser-leveled to a zero slope. Hence, although no physical boundaries were installed (nor were they practical) the system was hydraulically designed to minimize both surface and subsurface inter-plot flows. Site drainage rates, durations, and timings were controlled by the grower, consequently, hydraulic conditions at each site were considered to be typical of production management practices.

A continuous flow measuring device was installed at the head of each plot ditch. The device consisted of a set of 5-, 10-, and 15-cm-diameter PVC pipes passing through wooden or metal cut-off walls that blocked the plot ditch from the perimeter ditches. Hence, any flow into or out of the plot ditches had to pass through a culvert of known size. The PVC culverts were calibrated in a laboratory to yield relationships between discharge and the hydraulic head across the culverts. Continuous water level recorders were placed inside and outside the plot ditches to provide hydraulic head differentials across the culverts.

The first site (site 1) consisted of two treatments: sugarcane (plant cane, early December 1988) grown with standard commercial practices and fallow. Plots for each treatment were selected at random and replicated four times. The soil type was a Lauderhill muck (euic hyperthermic Lithic Medisaprist). Plots received no N in supplemental fertilizer. All eight plots received the same water management practices. At site 2, eight plots were planted to sugarcane in early December 1988. The soil type at this site was a Terra Ceia Muck (euic hyperthermic Typic Medisaprist). No N fertilizer was applied at the site. At site 3, which consisted of eight plots, radishes were grown from January to May and from October to December. No N fertilizer was applied during the crop seasons. Four of the plots were flooded fallow during the summer (June to September) the other four were in paddy rice. The final radish crop of the season was harvested during the middle of May 1989. A flood and drain-down cycle for pest and

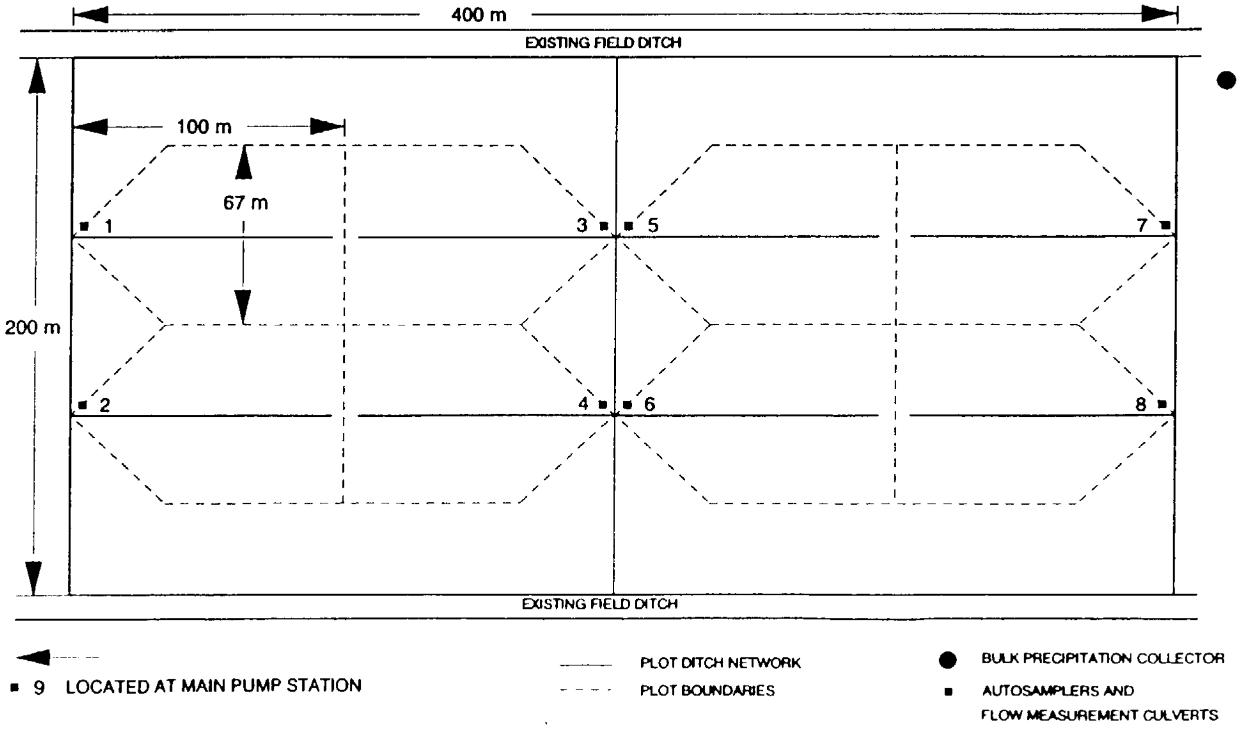

Figure 2–Test site layout used for screening BMPs.

weed control was performed in June 1989, prior to establishing the four-month flood period. The drain-down of the field prior to harvest occurred in September 1989. The final site (site 4) consisted of 12 plots planted to cabbage (*Brassica oleracea* L.), the first crop was planted during the period 9 to 13 January 1989, and harvested 4 to 12 May 1989. The second crop was planted between 28 to 30 August 1989. Heavy rains wiped out this crop. It was replanted 8 to 10 November 1989 and harvested 2 to 16 March 1989. The cabbage was grown using cultural practices typical of the EAA. The plots were side dressed with approximately 56 kg N ha^{-1} after planting. The soil types at sites 3 and 4 were Pahokee Muck (euic hyperthermic Lithic Medisaprist).

An ISCO 2900 automatic water sampler (ISCO, Inc., Lincoln, Nebr.) was installed in each plot ditch (fig. 2). The samplers were turned on manually when drainage events occurred. The samplers were programmed to collect 500 mL samples on 1-, 2-, 4-, or 8-h intervals, depending on the anticipated drainage event duration. Also, monthly grab samples were collected. The monitoring period began in January 1989 and ended in September 1990.

A bulk precipitation collector was installed at each of the four sites. Rainfall samples were collected during several events during the monitoring period.

Automatic water samplers were installed in three main farm canals, approximately 30 m upstream of the respective main farm pump stations serving the entire farm area where the sites were located. Samples were collected from the main farm canal at the same times that samples were collected in the plots.

All samples were retrieved from the field within 48 h of the collection of the first sample in the set. Autosampler bases were usually filled with ice at the time the samplers were turned on, to keep the water samples cool. However, when sampling was initiated at night, or during cold spells, ice was not used. Laboratory analyses began immediately upon retrieving samples from the field. Samples which could not be analyzed within a day were frozen. Vacuum filtered (0.45 μm polysulfone membranes) and unfiltered aliquots of each sample were digested using the persulfate digestion method (American Public Health Association, 1985). Analyses for NH_4^+, TKN, TDKN were conducted using a TRAACS 800 autoanalyzer (Technicon Instruments Corporation, Tarrytown, N.Y.) and the phenate method (Technicon Instruments Corporation, 1986; American Public Health Association, 1985). Nitrate (NO_3^-) was determined using an Autoanalyzer II (Technicon Instruments Corporation, Tarrytown, N.Y.) and the cadmium reduction method (Technicon Instruments Corporation, 1986; American Public Health Association, 1985).

Average event TN, NO_3^-, and NH_4^+ concentration time series were calculated by averaging the concentration time series for the four plots representing the same monitored condition to obtain a single concentration time series representative of the drainage event for a condition. The plot concentration time series were then averaged to obtain the drainage event average TN, NO_3^-, and NH_4^+ concentrations.

Nitrogen loadings were calculated for 1989. The plot drainage hydrographs for all the like treatments were averaged over time and flow volume time series were calculated. These time series were then multiplied by the drainage water TN concentrations over time to yield loadings from a representative plot. Loadings were then adjusted to a per hectare basis and reported for the 1989 calendar year.

RESULTS AND DISCUSSION

FIELD TN CONCENTRATIONS

Total nitrogen concentrations for the 10 sugarcane field water sample sets at site 1 averaged 10.12 mg L^{-1} (table 1). This was greater than the 6.05 mg L^{-1} TN concentration reported by CH2M-Hill (1978) for a sugarcane plantation. However, the data reported here may have been skewed upwards by high TN concentrations (up to 17.89 mg L^{-1}) from a single drainage event (6.5 cm rainfall) that occurred following several months of a prolonged dry period. The average TDKN, NO_3^-, and NH_4^+ concentrations for sugarcane site 1 were 5.39, 1.59, 0.58 mg L^{-1} (tables 2, 3, and 4), respectively.

The TN concentration average for the second sugarcane field (site 2) was 7.44 mg L^{-1} (table 1). This concentration is 1.39 mg L^{-1} greater than the values reported by CH2M-Hill (1978). The average TDKN, NO_3^-, and NH_4^+ concentrations for the site 2 sugarcane fields were 4.14, 2.17, and 0.37 mg L^{-1} (tables 2, 3, and 4), respectively.

Total nitrogen concentrations from the radish site (site 3) averaged 4.81 mg L^{-1} (table 1). This TN average was 0.69 mg L^{-1} lower than the 5.50 mg L^{-1} TN concentration for the generic vegetable farm reported by CH2M-Hill (1978). The average TDKN, NO_3^-, and NH_4^+ concentrations for radishes (site 3) were 2.56, 0.74, and 0.23 mg L^{-1} (tables 2, 3, and 4), respectively.

Total nitrogen concentrations from the cabbage site (site 4) averaged 14.42 mg L^{-1} (table 1). This TN average was 8.63 mg L^{-1} higher the 5.50 mg L^{-1} concentration for the generic vegetable farm reported by CH2M-Hill (1978).

Table 1. Total nitrogen concentrations from selected farm practices and in canals and precipitation

Condition	Muck Type	TN Concentration (mg L^{-1}) Average	Minimum	Maximum
Sugarcane 1	Lauderhill	10.12	3.00	28.50
Sugarcane 2	Terra Ceia	7.44	3.12	12.97
Radish	Pahokee	4.81	1.83	32.66
Cabbage	Pahokee	14.42	4.47	70.66
Drained fallow	Lauderhill	11.57	2.49	35.74
Flooded fallow	Pahokee	9.81	2.56	77.04
Main farm canals		5.08	1.38	16.60
Precipitation		1.27	0.47	2.79

Table 2. TDKN concentration from selected farm practices and in canals and precipitation

Condition	Muck Type	TDKN Concentration (mg L^{-1}) Average	Minimum	Maximum
Sugarcane 1	Lauderhill	5.39	2.32	10.03
Sugarcane 2	Terra Ceia	4.10	1.70	7.22
Radish	Pahokee	2.56	0.86	6.43
Cabbage	Pahokee	6.45	2.13	12.51
Drained fallow	Lauderhill	5.80	1.62	8.88
Flooded fallow	Pahokee	2.74	1.24	11.32
Main farm canals		2.85	0.85	7.13

Table 3. NO_3^--N concentrations from selected farm practices and in canals and precipitation

Condition	Muck Type	NO_3^--N Concentration (mg L^{-1}) Average	Minimum	Maximum
Sugarcane 1	Lauderhill	1.59	<0.04*	12.33
Sugarcane 2	Terra Ceia	2.17	0.26	8.98
Radish	Pahokee	0.74	<0.04*	4.31
Cabbage	Pahokee	4.59	<0.04*	32.10
Drained fallow	Lauderhill	1.71	<0.04*	14.20
Flooded fallow	Pahokee	1.04	<0.04*	9.37
Main farm canals		1.0	<0.04*	10.90
Precipitation		0.21	0.13	0.35

* Detection limit NO_3^--N = 0.04 mg L^{-1}.

Table 4. NH_4^+-N concentrations from selected farm practices and in canals and precipitation

Condition	Muck Type	NH_4^+-N Concentration (mg L^{-1}) Average	Minimum	Maximum
Sugarcane 1	Lauderhill	0.58	<0.02*	3.00
Sugarcane 2	Terra Ceia	0.37	<0.02*	1.23
Radish	Pahokee	0.23	<0.02*	1.06
Cabbage	Pahokee	1.18	0.03	3.32
Drained fallow	Lauderhill	0.65	<0.02*	3.15
Flooded fallow	Pahokee	0.69	<0.02*	6.02
Main farm canals		0.41	<0.02*	3.42
Precipitation		0.40	0.07	2.12

* Detection limit NH_4^+-N = 0.02 mg L^{-1}

This may be due to the major rainfall that occurred in September and the fact that CH2M-Hill (1978) monitored TN concentrations at a main farm canal serving 630 ha rather than at the field level. The average TDKN, NO_3^-, and NH_4^+ concentrations for cabbage were 6.45, 4.59, 1.18 mg L^{-1} (tables 2, 3, and 4), respectively.

Drained fallow plots (site 1) were included in the baseline study since a substantial amount of land in the EAA is fallow during a year, particularly during the summer months. The fallow land is generally drained during rainfalls according to the drainage requirements of the other crops in the same water management unit. The average TN concentration for the drained fallow site was 11.57 mg L^{-1} (table 1). The average TDKN, NO_3^-, and NH_4^+ concentrations were 5.80, 1.71, and 0.65 mg L^{-1} (tables 2, 3, and 4), respectively.

Four radish plots of the eight plots at site 3 were flooded fallow after the radish season which is a common practice in the EAA (Snyder, 1987). The average TN concentration in drainage water during the flooding and drain-down cycles was 9.81 mg L^{-1} (table 1). The average TDKN, NO_3^-, and NH_4^+ concentrations were 2.74, 1.04, and 0.69 mg L^{-1} (tables 2, 3, and 4), respectively.

MAIN FARM CANALS

MONTHLY AVERAGE TN CONCENTRATIONS

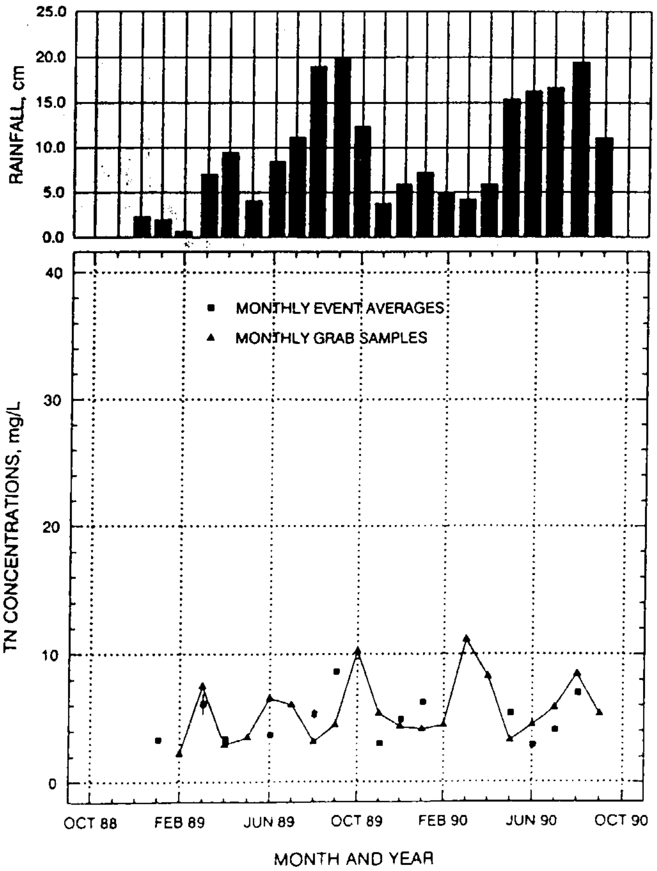

Figure 3–Monthly grab and event average TN concentrations with standard error bars for main farm canals.

DRAINED FALLOW FIELDS

MONTHLY AVERAGE TN CONCENTRATIONS

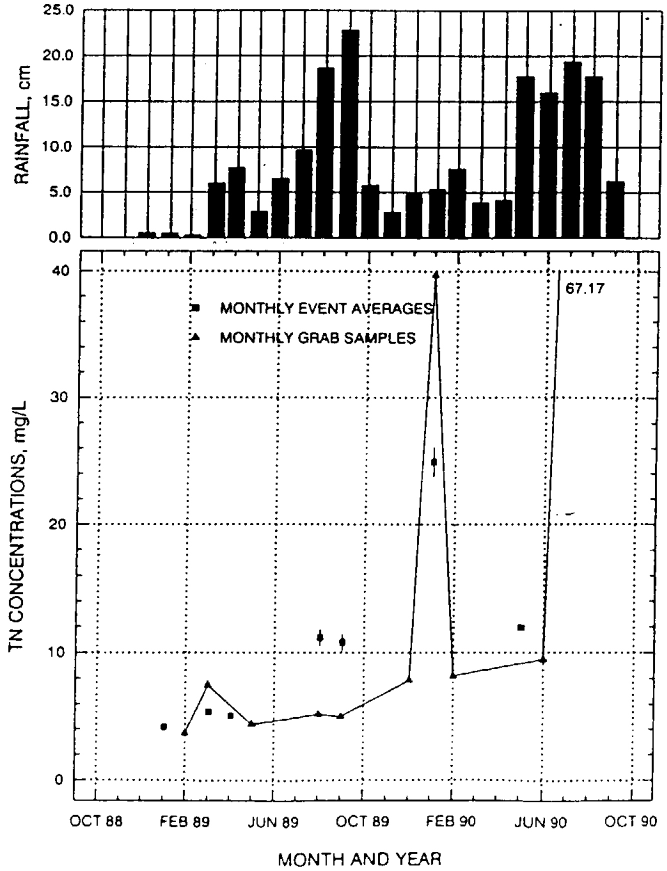

Figure 4–Monthly grab and event average TN concentrations with standard error bars for drained fallow plots.

MAIN RECEIVING CANAL TOTAL NITROGEN CONCENTRATIONS

An average TN concentration of 5.08 mg L^{-1} (table 1) was obtained from 28 events sampled on three main farm receiving canals. The drainage events were only a portion of the total number of events that occurred. The sampling events were, however, spaced through the year, with a higher frequency of sampling occurring during the rainy months. This average concentration is similar to the concentrations for vegetable farm and cattle ranch sites reported by CH2M-Hill (1978).

The average NO_3^- concentration measured in main receiving canals was 1.09 mg L^{-1}, or 21% of TN. Apparently, some dilution, denitrification, and/or assimilation of N occurred between the field ditches and the pump station on the main receiving canal as evidenced by the lower concentrations found near the main pump stations as compared to in-field values. Water in the open ditch conveyance system is exposed to multiple mechanisms for N adsorption and assimilation (i.e., plants and peat sediments). Some of the water may also have been introduced into the farm system during irrigation or by leakage through water control structures between the EAA canal and farm canal systems. It is speculated that during a drainage pumping event, the volume of water pumped off a farm is comprised primarily of water in the open ditch network and surface runoff. Only after extensive pumping will the water located in the soil profile begin to appear in samples collected at main pump stations.

BULK PRECIPITATION TN CONCENTRATIONS

Total nitrogen concentrations for bulk precipitation ranged from 0.47 to 2.79 mg L^{-1} (table 1), averaging 1.27 mg L^{-1}. The average TN concentration is lower than the 2.10 mg L^{-1} concentration reported by Waller and Earle (1975) and slightly higher than the concentrations reported by CH2M-Hill (1978). CH2M-Hill (1978) reported that insect contamination was practically eliminated when a nylon screen was placed over the mouth of the collection device and a loose glass-wool plug was inserted in the throat of the collection funnel. Waller and Earle (1975) indicated that insect contamination of samples occurred frequently. Insect contamination was not a problem in this study since rainfall collectors were placed in the fields during the rainfall and retrieved immediately afterwards.

The SFWMD data for a rainfall collector at pump station S-2 averaged 1.16 mg TN L^{-1} (CH2M-Hill 1978). This value compares favorably with the data collected during this project.

SEASONAL VARIATIONS IN TOTAL NITROGEN FOR SAMPLED CONDITIONS

Total nitrogen concentrations in main farm canals varied between 2 and 11 mg L^{-1} through the year. Total nitrogen

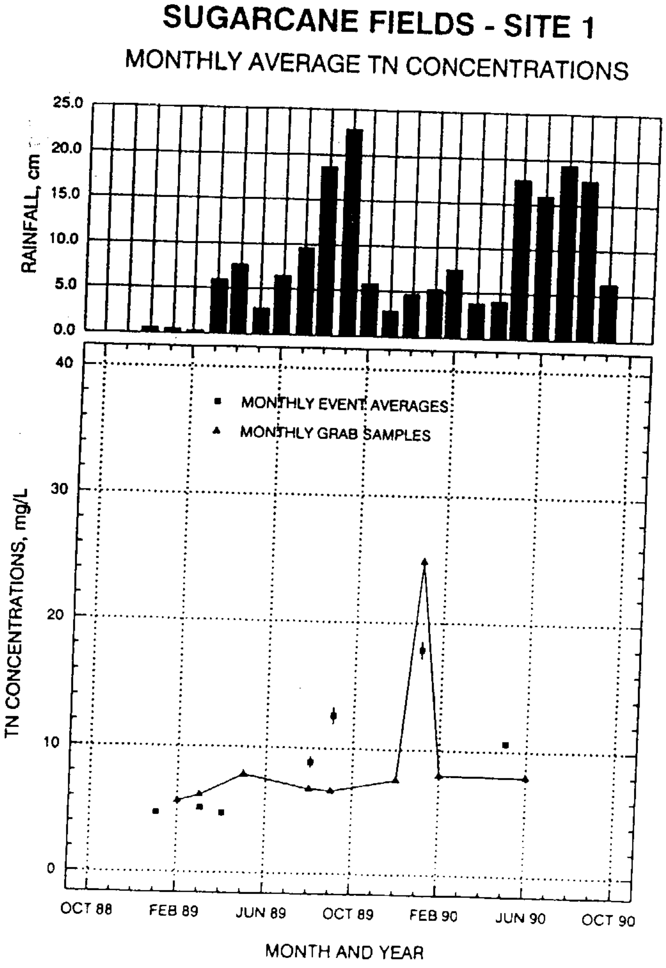

Figure 5–Monthly grab and event average TN concentrations with standard error bars for site 1 sugarcane plots.

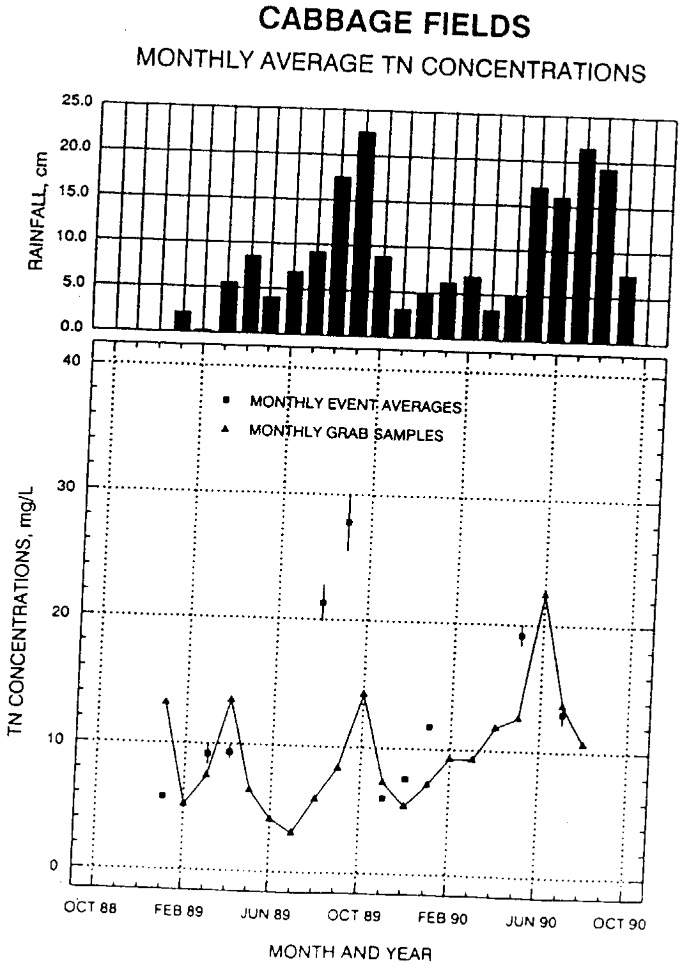

Figure 6–Monthly grab and event average TN concentrations with standard error bars for broadcast fertilized cabbage plots.

concentrations were generally elevated during the rainy season (fig. 3).

The average monthly TN concentrations in the drained fallow field plots (fig. 4) were similar to those in the main canals except in January 1990 and July 1990 when TN concentrations were very high in the field ditches. Total nitrogen concentrations peaked during the month with the highest rainfall in 1990.

Total nitrogen for sugarcane (site 1) drainage water was highest during January 1990 (fig. 5).

Average TN concentrations in drainage water from cabbage fields peaked in September 1989, when rainfall was relatively high (16 cm) (fig. 6). The fields had been maintained as drained fallow since cabbage was harvested in May. The September 1989 TN concentration was approximately 28 mg L^{-1}. This value is approximately double the September 1989 TN concentration for sugarcane at site 1. This high concentration coincided with the planting and fertilization of the second cabbage crop which occurred during the last few days of August 1989. Hence, it appears that the September 1989 TN concentrations were, at least in part, a direct result of fertilization.

Total nitrogen concentrations remained relatively consistent at the second sugarcane site (fig. 7). Concentrations peaked in March 1989 coinciding with the first substantial rainfall following a period of no precipitation.

The monthly TN concentration variations for the radish and flooded fallow fields are presented in figure 8. Total nitrogen peaked at 19.27 mg L^{-1} in September 1989. Total nitrogen concentrations were elevated in January 1990 due to a prolonged dry period followed by a substantial rainfall event. These data suggest that an initial flushing of the soil profile after vegetable cultivation, either by rainfall or pumping, will remove large amounts of TN from the soil profile.

NITROGEN CONCENTRATIONS DURING FLOODING AND DRAINING

The TN concentration distributions over time for the June flood and drain-down event following radish harvest are presented in figure 9. Concentrations of TN and TDKN were close in magnitude throughout the flood and drain-down cycle. Between 19 and 21 June, the flashboards that were placed in the main culverts serving the plots to hold the flood were removed and the plots were rapidly drained. Nitrogen concentrations peaked and were back to the predrainage concentrations within 30 h. The TN concentrations rose to nearly 14 mg L^{-1} during drain-down (fig. 9).

The TN concentrations over time, measured during the September drain-down following a 90-day flood, are presented in figure 10. Flood waters were allowed to subside naturally from 1 to 9 September 1989. On

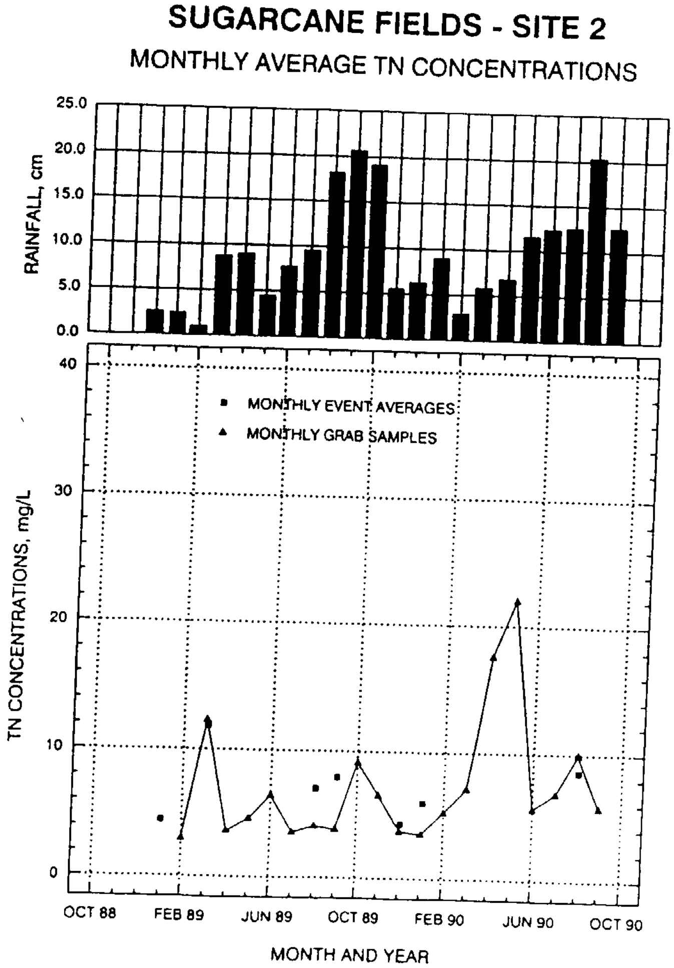

Figure 7–Monthly grab and event average TN concentrations with standard error bars for site 2 sugarcane plots.

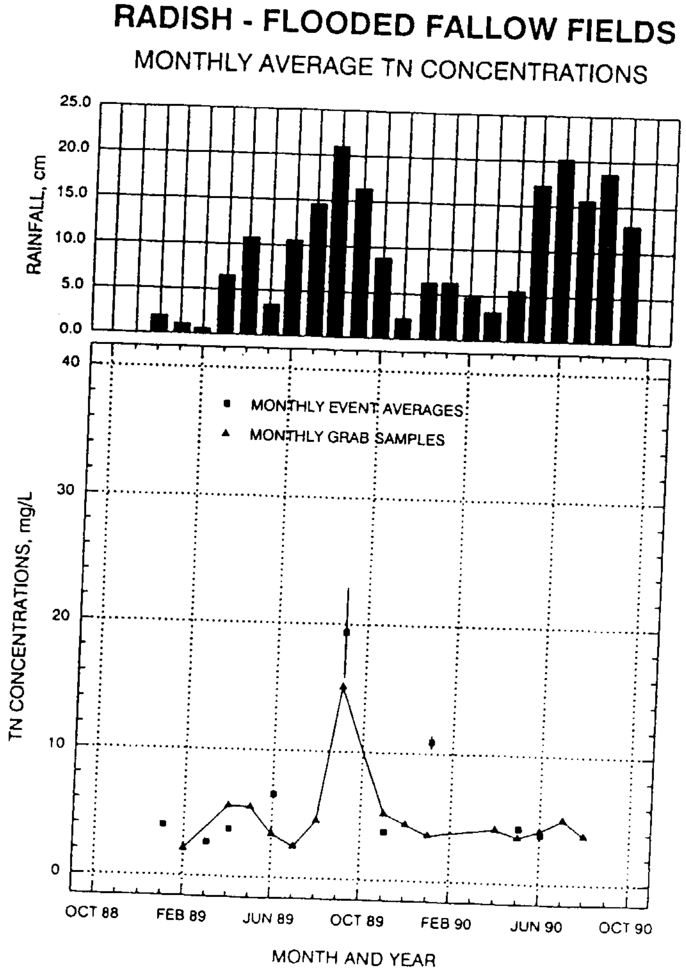

Figure 8–Monthly grab and event average TN concentrations with standard error bars for radish-flooded fallow rotation plots.

9 September 1989 the flashboards in the culverts serving the site were removed, drainage rates increased, and both TN and TDKN concentrations began to increase. Although TN concentrations approached 80 mg L^{-1}, TDKN concentrations remained below 10 mg L^{-1}, indicating an extreme increase in N attached to particulates.

NITROGEN LOADING

Total nitrogen loading rates for 1989 were 8.89, 9.65, 37.4, 11.64, 50.54, and 39.42 kg ha^{-1} for sugarcane (site 1), drained fallow, sugarcane (site 2), radish, flooded fallow, and cabbage fields, respectively (table 5). The loadings for radish and flooded fallow plots were for only a portion of the year since the two conditions occurred in rotation on the same fields. Adding the two loading rates yields a loading rate of 62.18 kg TN ha^{-1} for radish-flooded fallow rotation fields during 1989. The TN loadings from the plots were generally lower than those reported by CH2M-Hill (1978) for large farms in the EAA. The loading rates were consistent with figures reported by Wanielista (1976) and Brezonik and Fox (1976) for a variety of agricultural categories on mineral soils.

CONCLUSIONS

Cropping practices and field conditions in the EAA significantly influence drainage water TN concentrations. Mean annual TN concentrations ranged from a low of 1.83 mg L^{-1} for radish plots during drainage events to a high of 77.04 mg L^{-1} during the drain-down of radish-flooded fallow rotation plots. Rainfall TN concentrations during the monitoring period averaged 1.27 mg L^{-1}. Overall, nitrogen concentrations at the field level were higher than those measured at the main farm pump stations serving the area, indicating that denitrification, dilution, assimilation, and adsorption may be occurring between the field ditches and the pump station. Total nitrogen concentrations peaked during high rainfall months when drainage pumping is needed most.

Total nitrogen loading rates ranged from 8.89 kg TN ha^{-1} for sugarcane fields at site 1 to 62.18 kg ha^{-1} for radish-flooded fallow rotation fields. The low loading rates for the sugarcane and drained fallow fields at site 1 were the direct result of the extremely low amount of drainage pumping due to much lower than normal rainfall at the site.

The effects of applied N fertilizer did not become apparent in drainage waters except under conditions where there was a drainage event directly following an application of fertilizer.

Because N concentrations in drainage water vary directly with rainfall, reducing N loads at EAA discharge points will be difficult without reducing drainage water N concentrations. Nitrogen loads can be reduced by pumping less water off a farm, but this would increase the potential for flood damage to crops. Retaining water on-farm during the rainy season could also limit the ability of basin-scale

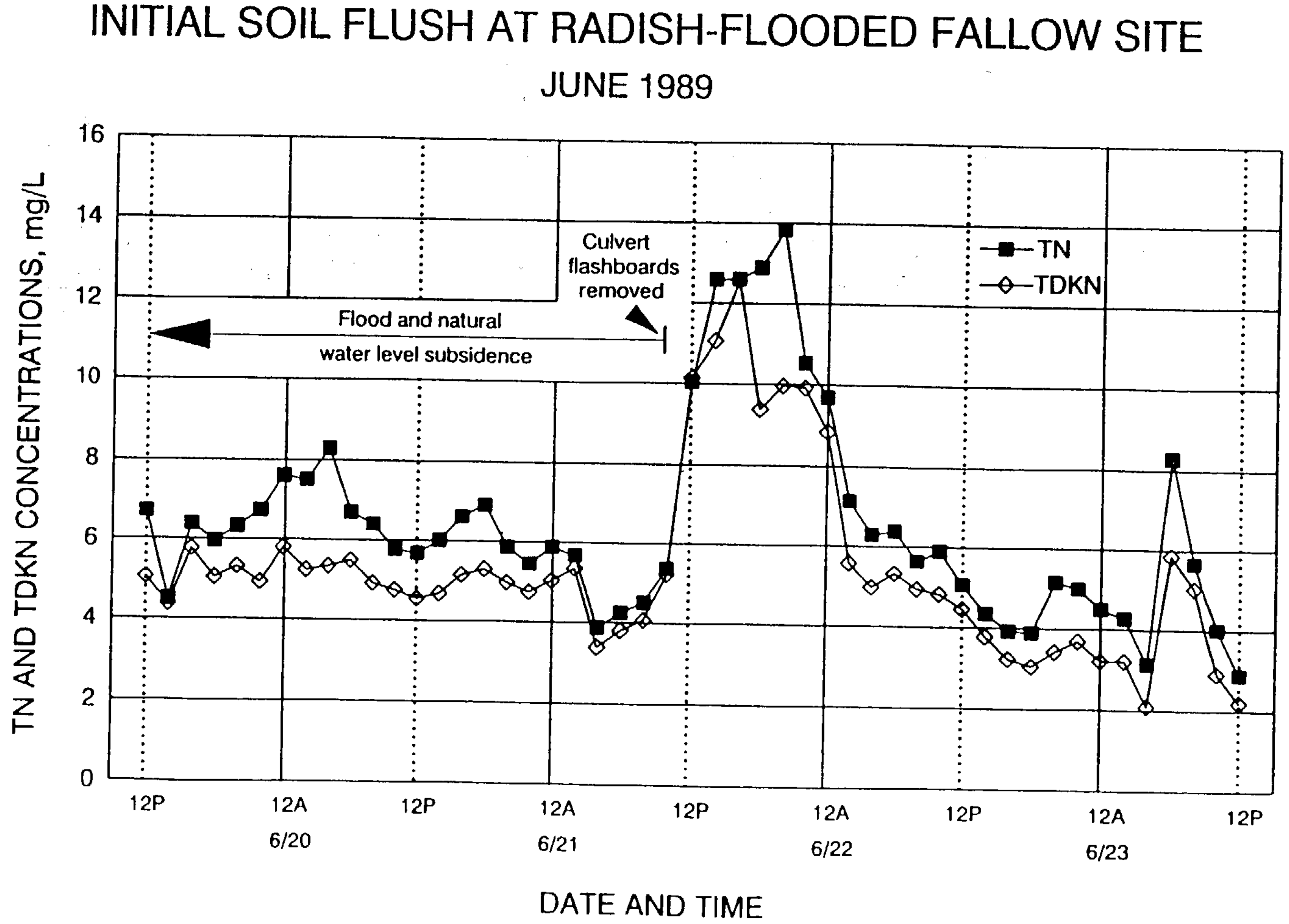

Figure 9–Distributions of TN and TDKN concentrations over time during the initial flushing of a fallow field following radishes.

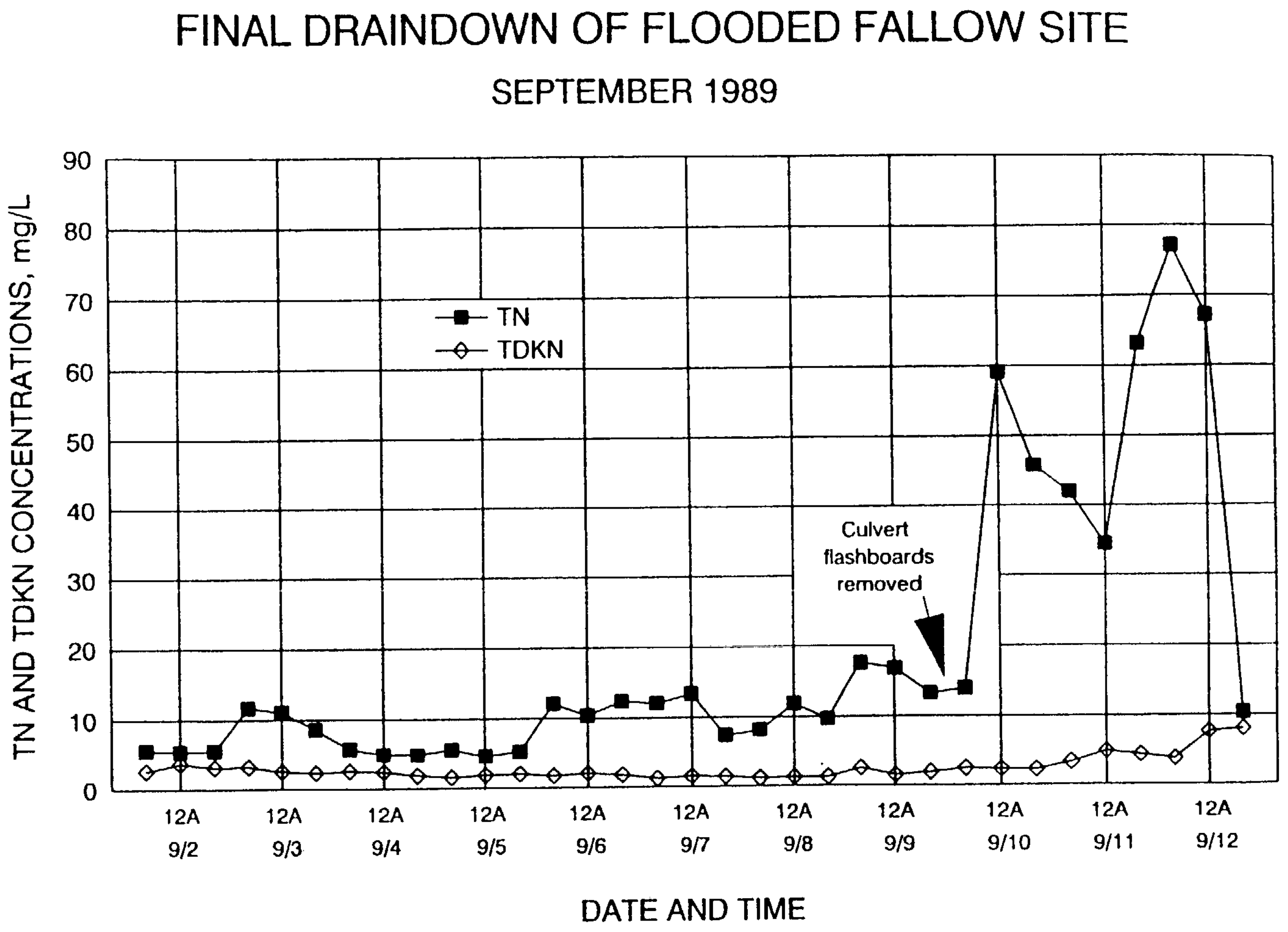

Figure 10–Distributions of TN and TDKN concentrations over time during the draindown of a flooded fallow field following radishes.

water managers to store water for supply. Therefore, efforts to reduce N loads at EAA discharge points should be directed towards reducing N concentrations on the farm.

The greatest potential for reducing N concentrations in EAA drainage water lies in management practices. Three management recommendations for reducing nitrogen concentrations in the drainage water are efficient usage of plant available N (applied and mineralizable sources), properly maintaining water tables to inhibit organic soil mineralization, and improved drainage practices. Fertility BMPs include, calibrated soil testing, banding of fertilizer, prevention of spills, split application of fertilizer, and use of slow release forms (Bottcher and Izuno, 1993). Fertilizer nutrients, particularly nitrogen, are used most efficiently if applied at the time when the crop need is the greatest. At this time, nitrogen is rapidly taken up by the plant, so leaching potential is greatly reduced. To minimize soil N mineralization, water management BMPs can be implemented to minimize water table fluctuations, retain drainage water on-farm, and retain vegetable field drainage water in sugarcane or fallow fields (Bottcher and Izuno, 1993). Existing drainage practices entail controlling farm water table according to the water level at the main farm pump station. By installing internal pumps, culverts, risers and boards, a grower can maintain the water level more uniformly, thus preventing overdrainage which is fundamental to reducing soil mineralization. Developing and implementing BMPs in these areas, and retaining water that would have otherwise been pumped off-site during flushing of the soil profile, also aid greatly in reducing N loading of area canals, Lake Okeechobee, and the WCAs.

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Table 5. Nitrogen loadings for selected farm practices and precipitation

Condition	Muck Type	TN ($kg\ ha^{-1}$)	Drainage Volume (cm)
Sugarcane (site 1)	Lauderhill	8.89	8.6
Radish*	Pahokee	11.64	24.1
Cabbage	Pahokee	39.42	23.9
Drained fallow	Lauderhill	9.65	8.6
Flooded fallow†	Pahokee	50.54	20.8
Sugarcane (site 2)	Terra Ceia	37.40	47.9
Precipitation		12.73	n/a

* Radishes were planted in rotation with flooding fallow. Hence the radish loading rate represents the time periods from January to May and October to December.

† Flooding fallow occurred in rotation with radishes. Hence the flooded-fallow loading rate represents the time period from June to September.

REFERENCES

American Public Health Association. 1985. Nitrogen. In *Standard Methods for Examination of Water and Wastewater*, eds. A. E. Greenberg et al., 373-412. Washington, D.C.: American Public Health Assoc.

Bottcher, A. B. and F. T. Izuno. 1993. Procedural guide for the development of farm-level best management practice plans for phosphorus control in the Everglades Agricultural Area. Gainesville: Florida Cooperative Extension Service, Univ. of Florida.

Brezonik, P. L., E. C. Blancher III, V. B. Myers, C. L. Hilty, M. K. Leslie, C. R. Kratzer, G. D. Marbury, B. R. Snyder, T. L. Crisman and J. J. Messer. 1979. Factors affecting primary production in Lake Okeechobee, Florida. Report No. 07-79-01, Florida Sugar Cane League, Clewiston, Fla. (Submitted).

Brezonik, P. L. and J. L. Fox. 1976. Analysis of eutrophication and water quality factors in the middle St. Johns River Basin. Report No. ENV-07-76-02. Gainesville: Dept. of Environmental Engineering Sciences, Univ. of Florida.

CH2M-Hill. 1978. Water quality studies in the Everglades agricultural area of Florida: Phase II. Project report submitted to the Florida Sugar Cane League, Clewiston, Fla.

Federico, A. C., F. E. Davis, K. G. Dickson and C. R. Kratzer. 1981. Lake Okeechobee water quality studies and eutrophication assessment. Tech. Pub. 81-2. West Palm Beach: South Florida Water Management District.

Florida State House of Representatives. 1991. Marjory Stoneman Douglas Everglades Protection Act. Tallahassee: Florida State Legislature.

LOTAC I. 1986. Final report of the Lake Okeechobee Technical Advisory Committee. Florida Dept. of Environment Regulation, Tallahassee, Fla. (Submitted).

LOTAC II. 1989. Final report of the Lake Okeechobee Technical Advisory Council. Governor of the State of Florida, the Secretary of the Florida Dept. of Environment Regulation, and the Governing Board of the South Florida Water Management District, Tallahassee, Fla. (Submitted).

Messer, J. J. and P. L. Brezonik. 1977. Nitrogen transformations in Everglades Agricultural Area soils and sediments. Subcontract report to CH2M-Hill.

Morris, T. 1975. Everglades agricultural area backpumping study in water quality models for understanding potential eutrophication in Lake Okeechobee, Florida, eds. F. G. Nordie and T. Gayle. Gainesville: Center for Wetlands, Univ. of Florida.

SFWMD. 1986. Lake Okeechobee water quality monitoring annual report: October 1984-September 1985. West Palm Beach: South Florida Water Management District.

————. 1988. Lake Okeechobee water quality monitoring program annual report: October 1985-September 1986. West Palm Beach: South Florida Water Management District.

————. 1990. Surface water improvement and management plan for the Everglades, draft. West Palm Beach: South Florida Water Management District.

Snyder, G. H., H. W. Burdine, J. R. Crockett, G. J. Gascho, D. S. Harrison, G. Kidder, J. W. Mishoe, D. L. Myhre, F. M. Pate and S. F. Shih. 1978. Water table management for organic soil conservation and crop production in the Florida Everglades. Bull. 801. Gainesville: Univ. of Florida Agric. Exp. Stn.

Snyder, G. H., ed. 1987. Agricultural flooding of organic soils. Bull. 870. Gainesville: Univ. of Florida Agric. Exp. Stn.

Swift, D. R. and R. B. Nicholas. 1985. Periphyton and water quality relationships in the Everglades Water Conservation Areas: 1978-1982. Technical Pub. 85-7. West Palm Beach: South Florida Water Management District.

Technicon Instruments Corporation. 1986. Industrial methods manual number 812-86T. Tarrytown, N.Y.: Technicon Instruments Corp.

United States District Court. 1991. Settlement Agreement for Case No. 88-1886-CIV-HOEVELER. Southern District of Florida. Miami.

Waller, B. G. and J. E. Earle. 1975. Chemical biological quality in part of the Everglades, southeastern Florida. Unpub. Report WRI 56-76. U. S. Geol. Survey, Tallahassee, Fla.

Wanielista, M. P. 1976. Nonpoint source effects. Report No. ESEI-76-1. Orlando: Florida Technological Univ.