Demonstration and Evaluation of South Dade Basin Vegetable Crop Best Management Practices:

Summer Cover Crops to Control Herbicide and Fertilizer Residue Leaching

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Sponsoring Agency

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EXECUTIVE SUMMARY

Production of vegetables, tropical fruits and ornamentals in Florida's Miami-Dade County contributes significantly to the region's economy. Estimates of total annual impact exceed $1 billion. Crop production in the county is centered on approximately 40,000 hectares that are located south of the city of Miami and between Everglades and Biscayne Bay National Parks. The area is referred to collectively in this report as the South Dade Basin (SDB).

Within the basin, pest pressure is intense and soils have low native fertility. To achieve economically sustainable yields growers depend on pesticides and fertilizers. SDB soils are also shallow, coarse textured and susceptible to agrichemical leaching. This makes the unconfined Biscayne aquifer which underlies the entire region vulnerable to pesticide and fertilizer residue contamination. The aquifer is the potable water source for most of the >3 million people residing in southeastern Florida. It has also been hypothesized that a main pathway for contaminant transport to surface water in SDB is leaching to groundwater, subsurface transport, and seepage into drainage canals. Thus, there is potential for adverse surface water quality impacts.

To better understand the environmental costs and benefits of SDB agriculture, the contribution that agrichemical use makes to non-point source pollutant (NPS) contamination of ground and surface water must be clearly defined. Data that are currently available do not allow a definitive assessment. There is also a need to demonstrate the efficacy of best management practices (BMPs) that control and reduce negative water quality impacts relative to current practices. These were the broad goals of the 3.5-year cooperative study described in this report. Cooperators were the USDA-ARS Southeast Watershed Research Laboratory and University of Florida Tropical Research and Education Center (TREC).

The study, which was initiated in November 1999, was conducted at the TREC research farm located in Homestead, FL. The study was designed to measure the extent to whether residues of agrichemicals used by SDB sweet corn (*Zea Mays L.*) growers are leached and the extent to which leaching may be reduced by use of a summer cover crop, Sunn Hemp (*Crotalaria juncea).* Sweet corn is an economically import crop in the SDB. The choice of Sunn Hemp was based on

prior work at TREC which demonstrated that Sunn Hemp is vigorous, provides dense cover, and has very high bio-mass production potential under SDB conditions. A network of monitoring wells which were installed near the centers of six 0.15 ha plots used for corn production were used to collect groundwater samples throughout the study. Samples were also collected from wells located hydraulically upgradient of the plots and a nearby canal (C-103). All samples were analyzed for residues of atrazine, 3 common atrazine environmental degradates. Groundwater samples were also analyzed for total and other forms of phosphorous and nitrogen. In total 4 corn crops were harvested during the study and >1700 water samples collected and analyzed.

Sweet corn yield and quality were found to be consistently high and compared favorably with the best SDB growers. None of the yield or quality parameters measured were significantly different when the cover and no-cover crop treatments were compared; however, in all cases there was a trend to higher yield and quality on plots managed with the cover crop. It can be safely concluded that use of Sunn Hemp as a summer cover crop did not reduce or otherwise negatively impact sweet corn yield or quality. BMPs are by definition practices which should increase or maintain yields while providing environmental benefits (Simonne et al., 2003). The study results confirmed that the first condition of this definition was met.

Water analysis results showed that the second condition, i.e. providing environmental benefits, was met. After BMP establishment an overall 40% reduction in combined atrazine residues, i.e. atrazine plus degradates, was detected in groundwater samples collected from wells located in cover crop plots when compared to those in the no-cover crop plots. Differences were statistically significant (P=0.10).

The predominant atrazine form detected in groundwater beneath all plots (with and without cover crop) was the degradate DEA. Its concentration was typically 2 to 3 times greater then atrazine. Relatively high DEA when compared to atrazine concentrations indicated that there was extensive atrazine degradation before leaching occurred. This was likely linked to SDB climatic and cropping patterns. The sweet corn crops in this study, like most vegetables in SDB, were produced during the winter dry season. Because rainfall rates are low during this period the potential for agrichemical leaching is also low. In turn it is likely that most of the atrazine that was applied prior to planting each crop remained in the surface soil where it was aerobically degraded or otherwise dissipated during the growing season. During the rainy season that followed, when leaching potential was substantially greater, little of the atrazine (or degradates) that was applied remained in the soil. Thus, levels detected in groundwater were low.

Low rates of leaching and high rates of atrazine degradation in soil inferred also help to explain why the levels of atrazine and degradates that were detected in ground water were generally low in all samples. In some cases combined atrazine residues, i.e. the sum of the concentrations of atrazine and degradates, exceeded drinking water maximum contaminant levels (MCL), but the number of samples in which MCLs were exceeded was very small (<1.0%). This was the case even though the study was conducted under what appeared to be worst-case leaching conditions. Repeated atrazine applications were made at standard agronomic rates to coarse textured soils where a highly productive unconfined groundwater resides 1 to 2 m below the soil surface.

In the case of the nutrient analysis results, quality control problems and or high background levels (in upgradient ground water) limited interpretations which could be made regarding leaching of fertilizer residues. Elevated NO_3-N levels were detected in samples collected from wells in no-cover crop plots. However, the overall difference between no-cover well results and those for the cover crop and upgradient well samples was small and not significant for both pre- and post-BMP periods. Failure to detect nitrate leaching and enrichment in groundwater due to fertilizer use in the study was likely due to the relatively high background levels detected in the upgradient wells. The geometric mean concentration NO_3-N concentration was 4.4 mg L^{-1}. A USGS study of groundwater quality in SDB reported that in the absence of urban or agricultural impacts, NO_3-N in SDB ground water was typically <0.05 mg L^{-1}.

Taken together results of the study demonstrated that planting a summer cover crop can help SDB sweet corn growers maintain and or increase crop yield and quality while reducing agrichemical leaching. For the herbicide atrazine, results were clear even though overall leaching rates were low whether a cover crop was used or not. A 40% reduction in leaching of combined atrazine residues was observed on plots where cover crops were planted and maintained. Data suggested that the cover crops also contributed to a trend toward lower NO_3-N leaching. However, high background NO_3-N levels in ground water at the study site made it difficult to quantitatively assess results.

In summary, the study demonstrated that cover crop use in SDB meets the basic requirements of a Best Management Practice (BMP). Crop quality and yield were maintained or increased and water quality was significantly improved. Currently, the economic feasibility of the cover crop used in the study, Sunn Hemp, is limited by seed cost. However, cost may be reduced if demands increase. Use of other cover crops also appears feasible. We conclude that adoption and implementation of this BMP can be expected to yield significant benefits and for corn and other SDB vegetable producers and the region's environment.

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ABBREVIATIONS

Agricultural Research Service	ARS
Analytical Research Laboratory	ARL
Best Management Practice	BMP
atmospheric pressure chemical ionization	APCI
sum of concentrations of atrazine, desethylatrazine, desisopropylatrazine, and hydroxyatrazine	ATSUM
sum of concentrations of atrazine, desethylatrazine, desisopropylatrazine	CLTRI
desethylatrazine	DEA
desisopropylatrazine	DIA
desethylatrazine/atrazine molar ratio	DAR
Everglades National Park	ENP
hydroxyatrazine	HA
high performance liquid chromatography	HPLC
mass spectrometry	MS
relative percent deviation	%RPD
solid phase extraction	SPE
South Dade Basin	SDB
Southeast Watershed Research Laboratory	SEWRL
South Florida Water Management District	SFWMD
Tropical Research and Education Center	TREC
United States Department of Agriculture	USDA
University of Florida	UF
United States Geological Survey	USGS

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This report is dedicated to our colleague, Dr. Herb Bryan, who died in a car crash on April 11, 2003. His untiring devotion to farmland conservation in Florida is greatly missed.

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1.0 PROJECT BACKGROUND

Production of ornamentals and vegetable and tropical fruit crops in Florida's Miami-Dade County contributes significantly to the region's employment and economy. Estimates of the total annual impact exceed $1 billion (Degner et al., 2001). Crop production in the county is centered on approximately 40,000 hectares south of the city of Miami and between Everglades and Biscayne Bay National Parks (Degner et al., 2002). The area is referred to collectively in this report as the South Dade basin (SDB).

Within the basin, agrichemical use is intense. Frequent pesticide applications to control insect damage, diseases, and weeds are required and growers must apply mineral fertilizers to achieve economically sustainable yields. In addition, soils principally used for farming are coarse textured and shallow, 10-20 cm to the limestone bedrock. Their susceptibility to leaching losses of both pesticides and fertilizers makes the Biscayne aquifer which underlies the entire region vulnerable to contamination. The aquifer is the potable water source for most of the >3 million people residing in southeastern Florida (McPherson et al., 2000). The aquifer is unconfined and shallow and within SDB resides in the highly porous limestone bedrock (Fish and Stewart, 1991). The water table surface is typically only 1-2 m below the land surface; thus there is only a relatively short distance to travel before pesticides or fertilizer residues that may be leached out of the root zone reach groundwater.

Another significant SDB hydrologic feature is the network of drainage canals. The canals which were constructed in the 1950s and 1960s intersect the water table surface. They contribute to accelerated stormwater runoff and short groundwater flow paths (Fish and Stewart, 1991). It has been hypothesized that a main pathway for contaminant transport to surface water in SDB is leaching to groundwater, subsurface transport, and seepage into drainage canals (Graham et al, 1997; Genereux and Slater, 1999). Thus agrichemical leaching could result in residue levels in surface water which may cause adverse ecologic impacts.

This has implications for on-going Everglades National Park (ENP) restoration efforts since there is widespread concern that nutrients and pesticides leached from farmland and transported to the Everglades are contributing to declines in sensitive Everglades' ecosystems (Anderson and Rosendahl, 1998; Alperts, 1999; Childers et al, 2003). To this point the focus has been on the Everglades Agricultural Area (EAA) located south of Lake Okeechobee and northwest of Miami. EAA farmers produce sugarcane and vegetables. Links between EAA crop production and levels of agrichemical residues in water draining the area have been intensively studied. This prompted development and implementation of best management practices (BMPs) which appear to be improving water quality (Izuno and Capone, 1995; Childers et al., 2003).

Comparatively, there has been little work within the SDB; however, existing water quality databases do document detection of agricultural pesticide residues in surface and groundwater (McPherson et al., 2000; Pfueffer and Matson, 2003) and elevated nitrate in groundwater beneath farm fields (McPherson et al., 2000). These data suggest that current farming practices may be contributing negatively to water quality. The study described in this report was designed to investigate this link for a commonly grown vegetable crop, sweet corn, and to determine whether or not a low cost BMP, planting a summer cover crop, has the potential to effectively reduce pesticide and nutrient levels in groundwater beneath farmers' fields.

2.0 PURPOSE AND SCOPE

To better understand the environmental costs and benefits of SDB agriculture, the contributions that agrichemical use by SDB farmers make to non-point source pollutant (NPS) contamination of ground and surface water must be clearly defined. Existing data do not allow a comprehensive assessment. There is also a need to devise and demonstrate the efficacy of best management practices (BMPs) that have the potential to control and reduce negative water quality impacts relative to current practices. These were the broad goals of the study described in this report.

Specifically, the report describes results of a 3.5-year investigation which measured the extent to which herbicides and fertilizers used in sweet corn production were leached to shallow groundwater and how residue levels could be reduced by use of a low-cost BMP, a summer cover crop. Sweet corn is grown on an estimated 10% of SDB land in vegetable crop production (Degner et al., 2002). A BMP commonly recommend to sweet corn and other SDB vegetable growers, maintaining vegetative cover on fields between crops, and turning cover crop residues into soil prior to planting was studied (Wang et al., 2002). The cover crop used was Sunn Hemp (*Crotalaria juncea*). Prior work conducted at the University of Florida Tropical Research and Education Center (TREC) demonstrated that Sunn Hemp is vigorous, provides dense cover, and has very high bio-mass production potential (Li et al., 1999). Its principal drawback is the relatively high cost of seeds. To some degree this is offset by its superior performance. It is also anticipated that costs will decrease if demands for seed increase.

Benefits attributed to use of Sunn Hemp and other cover crops are improved soil tilth, reduced erosion (wind and water), weed and disease control, and maintenance and or increases in soil organic matter and biological activity. In addition, cover crops also increase evapotranspiration during periods when leaching risks are high. We hypothesized that these factors would reduce pesticide and fertilizer leaching rates and contribute to improved SDB water quality.

3.0 DESCRIPTION OF STUDY SITE

The study was conducted at TREC which is located on about 60-ha of prime farmland 5 km northwest of the center of the city of Homestead, Florida and adjacent to the South Florida Water Management District (SFWMD) C-103 canal (Figures 1 and 2). TREC maintains approximately 50-ha in vegetable and tropical fruit production. A 4-ha block in an area where vegetables have historically been produced was set aside for this study. The study block location is indicated in Figure 2 and an aerial photograph is shown in Figure 3. As indicated in the photograph the area is essentially flat.

Figure 4 shows locations of the six 0.15-ha plots that were delineated within the 4-ha block and the 35 monitoring wells that were constructed. A well construction schematic is shown in Figure 5. The rectangular plots (27 by 47 m) were oriented so that the lengthwise dimension (47

Figure 1. Location of the University of Florida Tropical Research and Education Center (TREC), Homestead, FL.

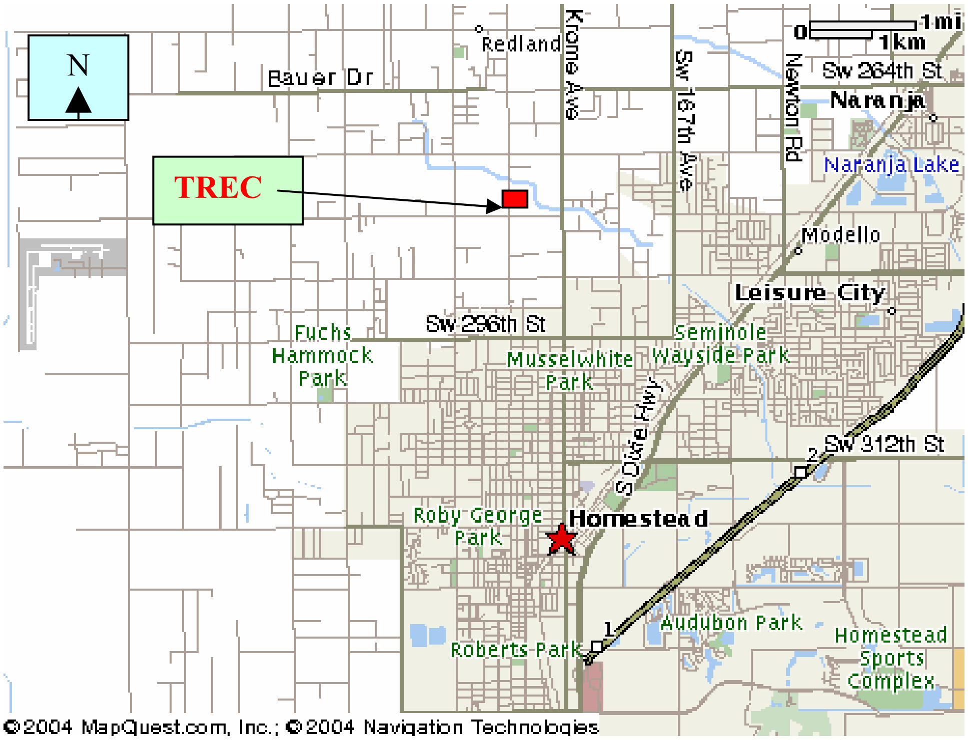

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Figure 2. Experimental block at TREC showing location of test plots relative to the C-103 canal and property boundaries.

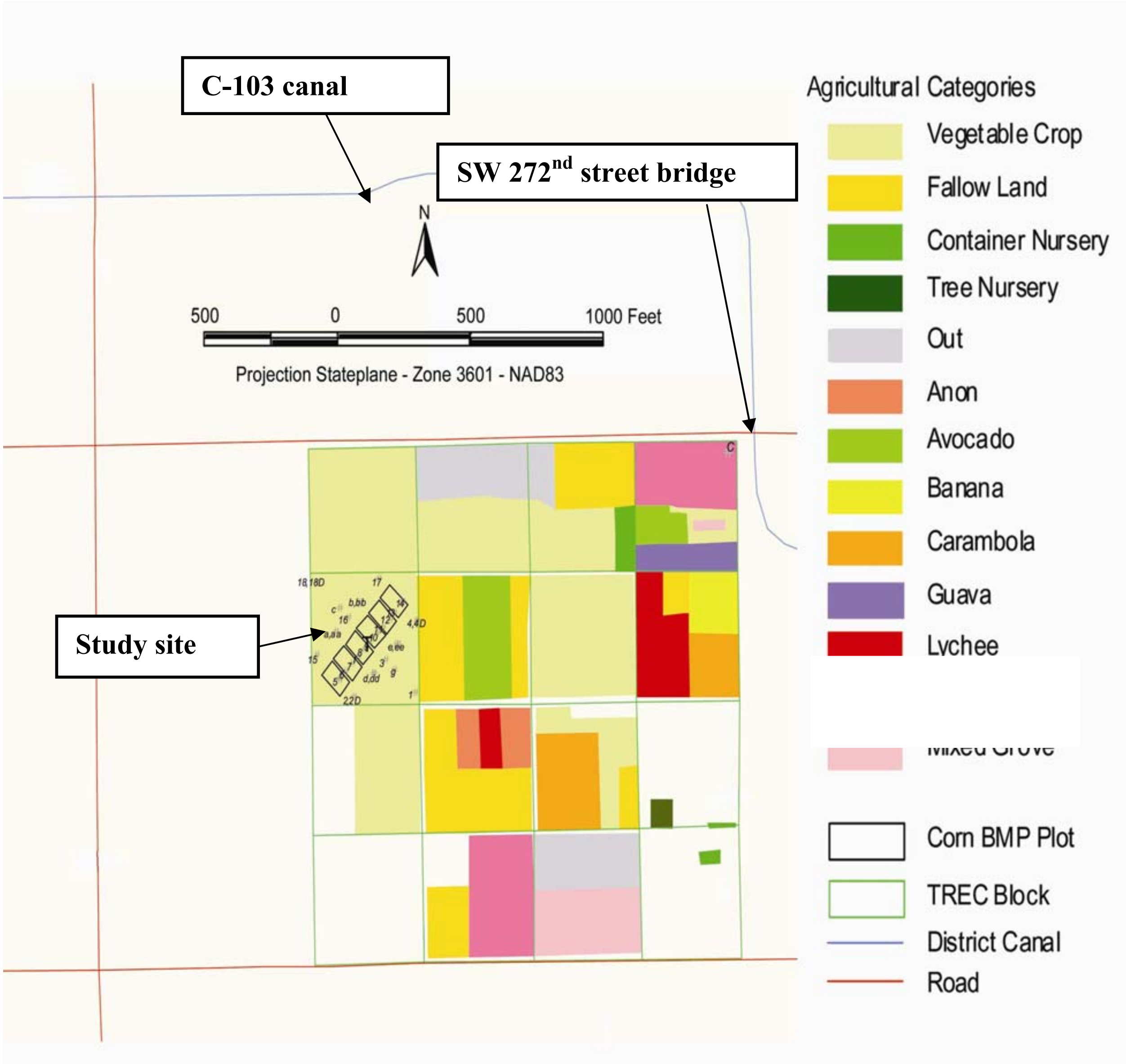


Figure 3. Aerial view of sweet corn BMP experimental block.

Figure 4. Layout of research plots and location of monitoring wells.

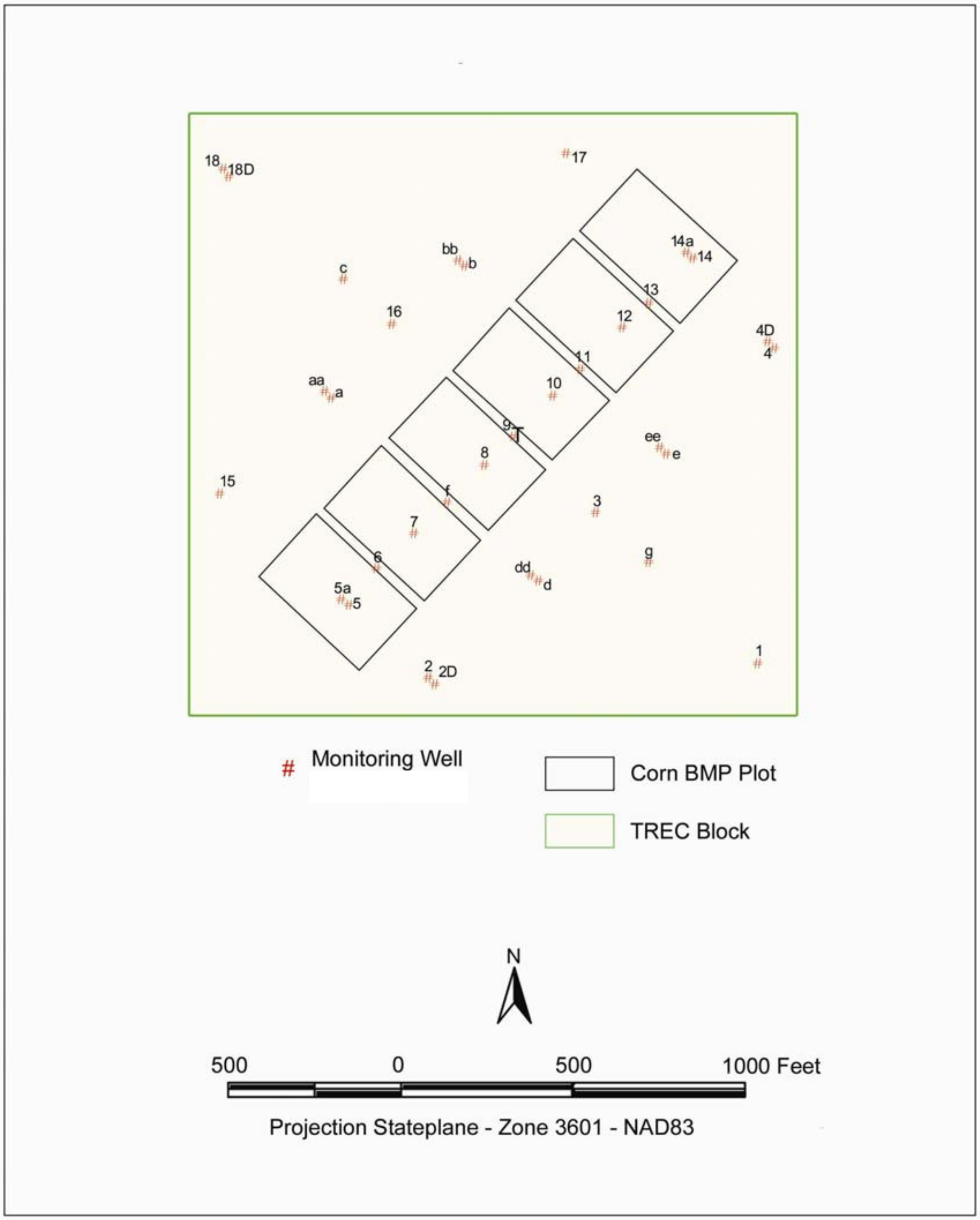
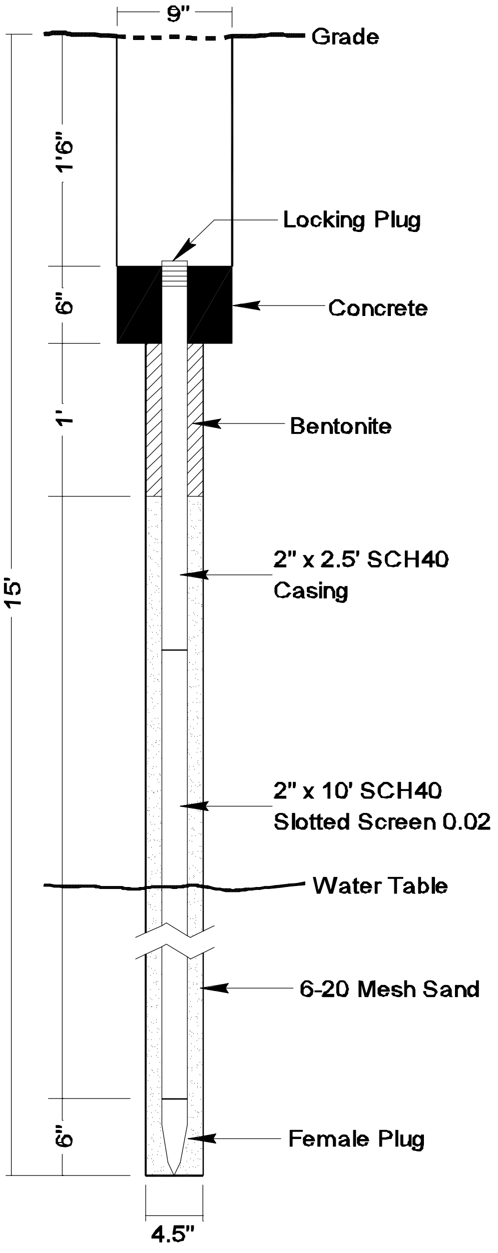


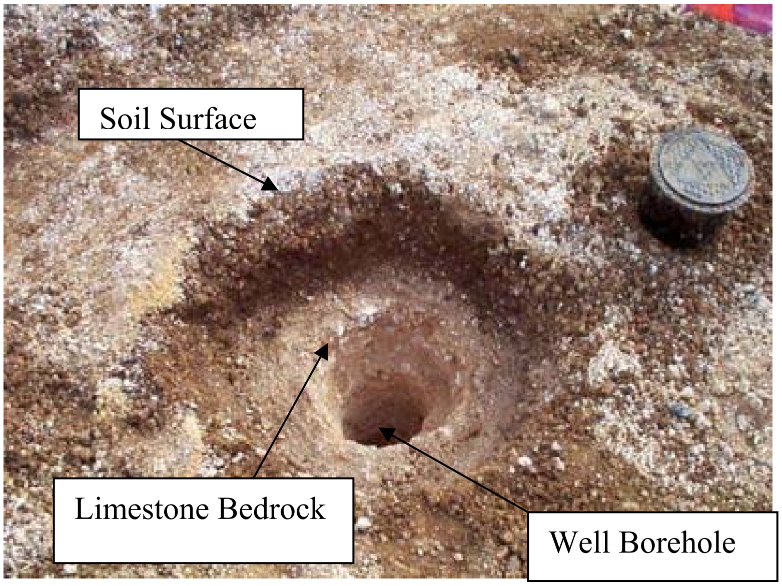
Figure 5. Monitoring well construction schematic.



m) paralleled the predominant direction of groundwater flow (S-SE) identified during a hydrogeologic investigation conducted at TREC in 1996 (ES&E, 1996). Flow direction was verified during the current study (see section 5.5 below). Water quality data described in this report, was obtained from analysis samples collected from wells that were located hydraulically upgradient (15,16,17,18) and in the centers of the plots (5,7,8,10,12,14). Once plots were delineated and well construction completed each of the 6 plots were randomly assigned to one of two treatment groups. The groups were designated cover crop and no-cover crop. There were three replicates in each treatment group.

The soil at the study site is classed in the Krome series. It is made-soil in the sense that it was developed from rock-plowing the underlying porous limestone bedrock. Krome soils are used for fruit and vegetable crops and urban and residential development (USDA-NRCS, 2004). Figure 6 is a photograph showing the soil surface, exposed limestone bedrock and a well borehole on one

Figure 6. Photograph showing the soil surface, exposed limestone bedrock and a monitoring well borehole on a research plot.



of the plots is shown in Figure 6. Two weeks prior to planting the first corn crop in the fall of 1999, a composite soil sample was collected from each plot.

All soil samples were sieved using a 2 mm stainless steel screen. Material retained and passing the sieve was weighed. The percent of total sample weight >2 mm (retained) and <2 mm (passing) is reported in Table 1 in addition to results of soil characterization tests performed on the <2 mm fraction. These data are within the normal range for Krome soils (Y. Li, University of Florida, personal communication). The most notable soil characteristics in the context of interactions with pesticides was the very low organic carbon content (<1%) and high fraction >2 mm. This translates to very low capacity for the soil to bind pesticides. These properties also explain why Krome soils have low water holding capacity 0.08-0.12 cm cm^{-1} of soil and rapid permeability (1.5 - 5.1 cm hr^{-1}) (USDA-NRCS, 2004).

Table 1. Physical-chemical properties of soil collected on research plots prior to planting the 1st sweet corn crop.[§]

property	units	range
<2 mm	%	40-58
>2 mm	%	42-60
sand	%	56-62
silt	%	18-28
clay	%	16-24
pHw	pH unit	7.8-8.1
organic carbon[†]	%	0.6-0.8
organic nitrogen	%	0.06-0.07
calcium[‡]	mg kg^{-1}	530-550
iron[‡]	mg kg^{-1}	0.3-0.8
potassium[‡]	mg kg^{-1}	21-47
phosphorous[‡]	mg kg^{-1}	3.7-6.5

[§] The fraction of the soil passing a 2-mm sieve was submitted to the University of Georgia Soil Testing Laboratory for analysis; [†]computed (organic nitrogen * 12); [‡] based on amount extracted in Mehlich-3 solution.

4.0 CROP MANAGEMENT

Sweet corn (*Zea Mays L.*) was planted on all plots in October-November each year and harvested the following January-March at maturity (about 100 days). After harvest, all plots were mowed and disced. Sunn Hemp (*Crotalaria juncea*) was then planted on plots in the cover crop treatment block. The seeding rate was ≈55 kg ha^{-1}. In 2000 and 2001, Sunn Hemp seed was purchased from a commercial supplier (Peaceful Valley Farm Supply, Nevada City, CA). In 2002, seed was donated by the USDA-NRCS. The variety, Tropic Sun, was produced in Hawaii. A photo of a typical mid-season Sunn Hemp stand on a cover crop plot is shown in Figure 7. A bare no-cover crop plot is shown in the foreground of the picture. Plots in the no-cover treatment group were left fallow. In October of each year, the cover crop plots were mowed. The residue was then worked into the soil by repeated discing. The no-cover crop plots were disced and prepared for planting at the same time.

Figure 7. Photograph of mid-season (July) Sunn Hemp stand on a cover crop plot (area in foreground is a no-cover crop plot).

A record of inputs including irrigation rates, planting and harvest dates, and application of pest control chemicals and fertilizers for the 4 sweet corn crops produced between 1999 and 2003 are complied in Tables 2 to 5. Types and amounts of pesticides and fertilizers used reflected commercial grower recommendations (USDA-OPMP, 1999 and advice from Miami-Dade County agricultural extension agents (T. Olzyck and M. Lamberts, personal communication). A preemergence atrazine application was made on all plots at the recommended label rate each year.

Table 2. Sweet corn Management: 1999-2000.

date	task	note
22-Nov-99	apply Atrazine® 4L and cultivate	2.2 kg ha^{-1}
29-Nov-99	plant sweet corn, apply fertilizer	variety: Attribute
02-Dec-99	install overhead irrigation, irrigate	17 mm
03-Dec-99	irrigate 2.5 h	irrigate for germination
06-Dec-99	irrigate 2 h	17 mm
09-Dec-99	irrigate 2 h	17 mm
10-Dec-99	irrigate 1 h irrigation test by Mobile Irrigation Lab	8.5 mm
13-Dec-99	irrigate 2 h	17 mm
16-Dec-99	irrigate 2 h	17 mm
20-Dec-99	irrigate 0.5 h liquid fertilizer applied	4.2 mm
23-Dec-99	spray Dithane® and Ambush®	
27-Dec-99	irrigate 2 h and cultivate	17 mm
28-Dec-99	cultivate	
29-Dec-99	drench with liquid fertilizer	
31-Dec-99	irrigate 2 h	17 mm
03-Jan-00	irrigate 2 h	17 mm
06-Jan-00	irrigate 2 h	17 mm
10-Jan-00	irrigate 2 h	17 mm
11-Jan-00	drench with liquid fertilizer/irrigate	
13-Jan-00	irrigate 0.5 h and apply liquid fertilizer	4.2 mm
04-Feb-00	spray Tilt® and Ambush®	
15-Mar-00 (estimated)	harvest corn	yield and quality data not collected
12-May-00	plant Sunn Hemp seed source: Peaceful Valley Farm	

Table 3. Sweet corn management: 2000-2001.

Date	task	note
12-Oct-00	apply Atrazine® 4L	2.2 kg ha^{-1}
19-Oct-00	plant sweet corn and incorporate fertilizer (8:16:18)	Variety: Attribute fertilizer rate = 440 kg ha^{-1}
23-Oct-00	irrigate 2 h	17 mm
26-Oct-00	irrigate 2 h	17mm
1-Nov-00	replant skips	
3-Nov-00	drenched with starter solution Keyplex®	
6-Nov-00	irrigate for 2 h	17 mm
7-Nov-00	spray Tilt® and Ambush®	
8-Nov-00	sidedress fertilizer (12:6:8)	fertilizer rate = 770 kg ha^{-1}
9-Nov-00	cultivate and irrigate 2 hrs	
13-Nov	irrigate 2 h	17 mm
16-Nov-00	irrigate 2 h spray Lorsban® 4E	17 mm
17-Nov-00	drenched Ironplex	
20-Nov-00	irrigate 2 h	17 mm
23-Nov-00	irrigate 2 h	17 mm
24-Nov-00	spray Ambush®	
27-Nov-00	irrigate 2 h	17 mm
28-Nov-00	drench with Ironplex®	
30-Nov-00	irrigate 2 h	17 mm
1-Dec-00	spray Lorsban® 4E and Tilt® drench with Ironplex®	
4-Dec-00	irrigate 2 h	17 mm
7-Dec-00	irrigate 2 h	17 mm
12-Dec-00	spray Lorsban® 4E and Tilt® drench with Ironplex®	
14-Dec-00	irrigate 1 h	9 mm
15-Dec-00	spray Lorsban® 4E and Tilt®	
18-Dec-00	irrigate 2 h	17 mm
19-Dec-00	spray Lorsban® 4E	
21-Dec-00	irrigate 2 h	17 mm
22-Dec-00	spray Lorsban® 4E and Ambush®	
26-Dec-00	irrigate 2 h, spray Lorsban® 4E	17 mm
29-Dec-00	irrigate for 2 h, spray Lorsban® 4E	17 mm
31-Dec-00	irrigate for 2 h	17 mm
1-Jan-01	irrigate for 6.5 h	55 mm, frost protection
17-Jan-01	harvest	
4-April-01	plant Sunn Hemp (Peaceful Valley Farm)	

Table 4. Sweet corn management: 2001-2002.

date	task	note
16-Nov-01	apply Atrazine® 4L and Dual® II	atrazine 2.2 kg ha-1 metolachlor 1.1 kg ha-1
28-Nov-01	plant corn and fertilize with 8:16:16	corn variety: Attribute® fertilizer rate=440 kg ha^{-1}
29+30-Nov-01	irrigate 4.5 h	38 mm (for germination)
03-Dec-01	irrigate 2 h	17 mm
06-Dec-01	irrigate 2 h	17 mm
10-Dec-01	irrigate 2 h	17 mm
12-Dec-01	drench with starter solution and IronPlex®	
14-Dec-01	irrigate 2 h	17 mm
17-Dec-01	irrigate 2.5 h	21 mm
19-Dec-01	spray Ambush®	
20-Dec-01	irrigate 2 h	17 mm
24-Dec-01	irrigate 2 h	17 mm
28-Dec-01	fertilize with 12:6:8 and cultivate	fertilizer rate=770 kg ha^{-1}
29-Dec-01	irrigate 2 h	17 mm
31-Dec-01	irrigate 2 h, spray Ambush®	17 mm
03-Jan-02	irrigate 0.5 h	5 mm
04-Jan-02	spray Ambush®	
07-Jan-02	irrigate 2 h	17 mm
10-Jan-02	irrigate 2 h	17 mm
11-Jan-02	spray Ambush® and Tilt®	
14-Jan-02	irrigate 2 h	17 mm
16-Jan-02	irrigate 2 h and fertilize with 12:6:8	fertilizer rate=770 kg ha^{-1}
17-Jan-02	spray with Ambush® and Tilt®	
21-Jan-02	irrigate 2 h, spray Lorsban® 4E and Tilt®	17 mm
24-Jan-02	irrigate 2 h	
25-Jan-02	spray Lorsban® 4E and Tilt®	17 mm
28-Jan-02	irrigate 2 h	17 mm
29-Jan-02	spray Lorsban® 4E and Tilt®	
31-Jan-02	irrigate 2 h	17 mm
02-Feb-02	spray Lorsban® 4E	
04-Feb-02	spray Lorsban® 4E and Tilt®	
05-Feb-02	irrigate 2 h	17 mm
07-Feb-02	irrigate 2 h	17 mm
08-Feb-02	spray Lorsban® 4E	end spray program
11-Feb-02	irrigate 2 h	17 mm
14-Feb-02	irrigate 2 h	17 mm
18-Feb-02	irrigate 2 h	17 mm
21-Feb-02	irrigate 2 h	17 mm
25-Feb-02	irrigate 2 h	17 mm
28-Feb-02	irrigate 2 h	17 mm
04-Mar-02	Harvest and grade corn	
26-Jun-02	plant Sunn Hemp seed source: USDA-NRCS (Hawaii)	

Table 5. Sweet corn management: 2002-2003.

Date	task	note
20-Nov-02	spray Atrazine® 4L and Dual® II	atrazine=2.2 kg ha-1 metolachlor=1.1 kg ha-1
3-Dec-02	fertilize with 8-16-16	fertilizer rate=440 kg ha^{-1}
4-Dec-02	fertilize with 8-16-16 and plant	fertilizer rate=440 kg ha^{-1} corn variety= Attribute®
5-Dec-02	irrigate3 h	25 mm
6-Dec-02	irrigate3 h	25 mm
13-Dec-02	irrigate3 h	25 mm
17-Dec-02	irrigate3 h	25 mm
18-Dec-02	apply starter solution and Keyplex®	
19-Dec-02	irrigate 2 h and spray Ambush®	17 mm
27-Dec-02	irrigate 2 h	17 mm
31-Dec-02	fertilize with 8-16-16 and spray Ambush®	fertilizer rate=880 kg ha^{-1}
3-Jan-03	irrigate 2 h and spray Ambush®	17 mm
6-Jan-03	spray Ambush®	
7-Jan-03	irrigate 2 h	17 mm
10-Jan-03	irrigate2 h	17 mm
13-Jan-03	irrigate 2 h	17 mm
18-Jan-03	spray Ambush® and Tilt®	
19-Jan-03	irrigate 5 h	42 mm, frost protection
20-Jan-03	irrigate 6 h	51 mm, frost protection
21-Jan-03	fertilize with 8-16-16	fertilizer rate=880 kg ha^{-1}
22-Jan-03	irrigate 2 h	17 mm
27-Jan-03	irrigate 2 h	17 mm
29-Jan-03	irrigate 2 h and spray Lorsban® 4E and Tilt®	17 mm
3-Feb-03	irrigate 2 h and spray Lorsban® 4E	17 mm
6-Feb-03	irrigate 2 h	17 mm
10-Feb-03	irrigate 2 h	17 mm
13-Feb-03	irrigate 2 h and spray Lorsban® 4E	17 mm
17-Feb-03	irrigate 2 h	17 mm
19-Feb-03	spray Ambush® and Tilt® and apply Ironplex®	
20-Feb-03	irrigate 2 h	17 mm
24-Feb-03	irrigate 2 h	17 mm
25-Feb-03	spray Ambush® and Tilt® and apply Ironplex®	
27-Feb-03	irrigate 2 h	17 mm
3-March-03	irrigate 2 h and spray Ambush® and Tilt® and apply Ironplex®	17 mm
6-March-03	irrigate 2 h	17 mm
11-March-03	irrigate 2 h and spray Ambush® and Tilt® and apply Ironplex®	17 mm
14-March-03	harvest and grade corn	

5.0 HYDROLOGIC MONITORING AND WATER SAMPLE COLLECTION AND HANDLING

5.1 On-line Hydrologic Data Sources. The Florida Agricultural Weather Network (FAWN) maintains a weather station at TREC. A continuous data record starting in 1997 is available on-line at http://fawn.ifas.ufl.edu/. Another TREC on-line hydrologic data resource is the continuous record of water table elevation available from a well maintained by the U.S. Geological Survey (USGS) at TREC. Data are updated daily and posted on-line at http://waterdata. usgs.gov/fl/nwis/uv/?siteno=253029080295 601&PARAmeter_ cd=72019, 72020. Daily precipitation and average water table elevation obtained from these sources are plotted for the entire study period in Figure 8. Dates when water samples were collected from monitoring wells and dates and amounts of atrazine applied are also shown.

5.2 Water sample collection. A complete record of all water samples collected is provided in Table 6. Samples identified as scheduled were obtained on preprogrammed intervals. In the period November 1999 to May 2000, this was once per month for pesticide residue analysis samples. Thereafter the collection rate was increased to 2 times per month. In total 75 scheduled sample sets were collected during the study. All included one sample from wells 1 to 18 (locations shown in Figure 4) and a surface water sample from the C-103 canal. Wells were purged (≈40 L) with a gasoline driven pump before samples were secured with a PVC bailer. The same bailer was used to collect canal samples from the bridge on SW 272nd street near the northeast corner of the TREC property (see Figure 2). For quality control purposes samples from well 7 were collected in triplicate and a field blank prepared with distilled-deionized water was included with each sample set. Pesticide sample containers were 500-mL glass bottles that were sealed with Teflon-lined screw caps.

Samples for nutrient analysis were collected at the same locations on the same schedule using the same equipment. Exceptions included the following. The first nutrient sample set was not collected until 11-January-2000. This was 6 weeks after planting the 1st sweet corn crop.

Thereafter samples were collected once per month until January 2002. In addition replicate samples from well 7 and canal samples were not collected. Containers used were polyethylene

Figure 8. Daily precipitation, water table elevation, dates of water sample collection and atrazine application and atrazine application rate.

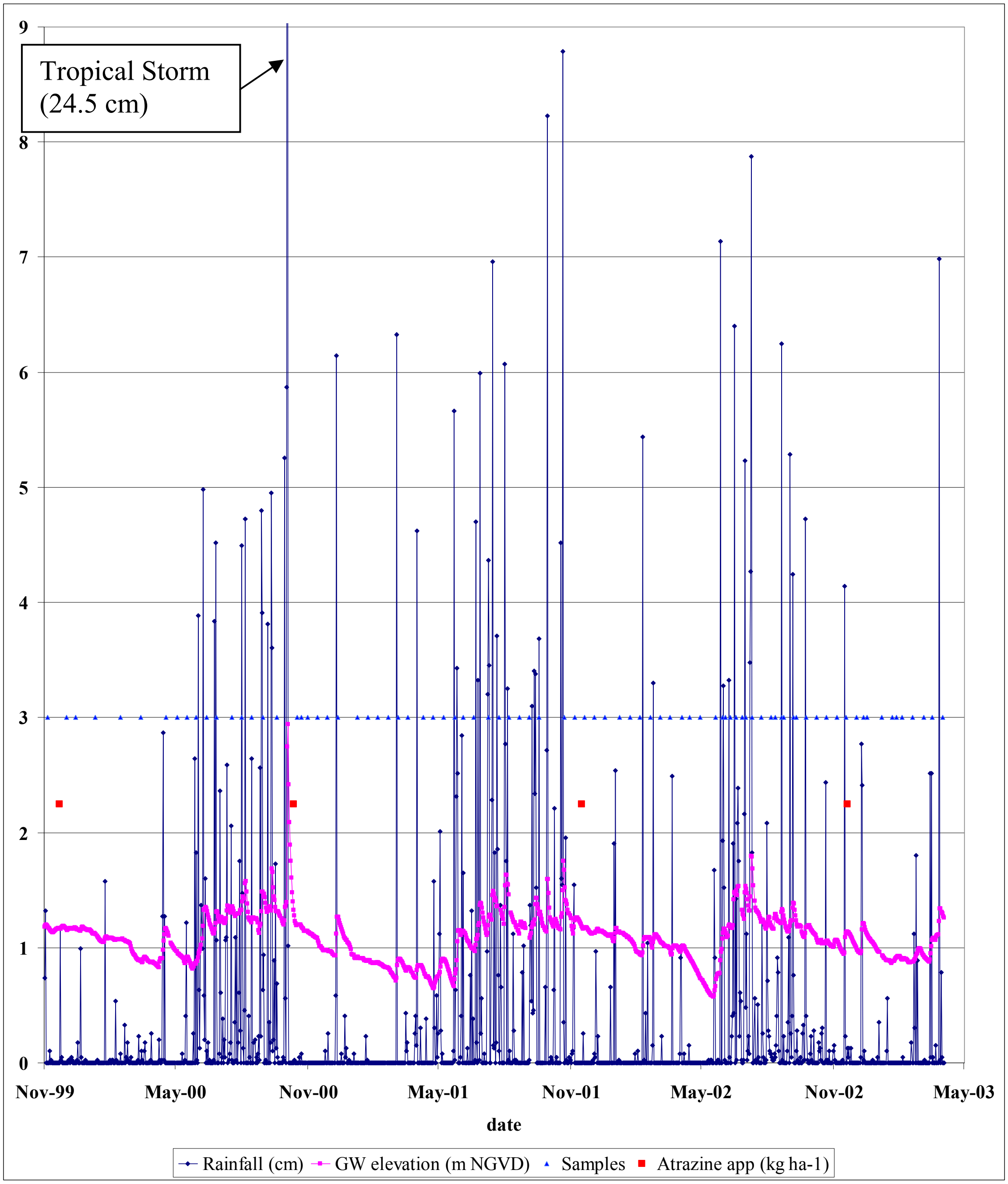


Table 6. Water sample collection record and schedule of analysis: 1999-2003.

date	nutrient	pesticide	notes
5-Nov-99	ns	X	background - scheduled
2-Dec-99	ns	X	scheduled
14-Dec-99	ns	X	scheduled
11-Jan-00	X	X	scheduled
15-Feb-00	X	X	scheduled
14-Mar-00	X	X	scheduled
18-Apr-00	X	X	scheduled
3-May-00	ns	X	scheduled
17-May-00	X	X	scheduled
30-May-00	ns	X	scheduled
13-Jun-00	X	X	scheduled
27-Jun-00	ns	X	scheduled
18-Jul-00	X	X	scheduled
1-Aug-00	ns	X	scheduled
15-Aug-00	lost in transit	X	scheduled
30-Aug-00	ns	X	scheduled
19-Sep-00	X	X	scheduled
17-Oct-00	X	X	scheduled
23-Oct-00	ns	X	scheduled
14-Nov-00	X	X	scheduled
28-Nov-00	ns	X	scheduled
12-Dec-00	X	X	scheduled
9-Jan-01	X	X	scheduled
23-Jan-01	ns	X	scheduled
6-Feb-01	X	X	scheduled
20-Feb-01	ns	X	scheduled
6-Mar-01	X	X	scheduled
20-Mar-01	ns	X	scheduled
10-Apr-01	X	X	scheduled
24-Apr-01	ns	X	scheduled
7-May-01	X	X	scheduled
24-May-01	ns	X	scheduled
5-Jun-01	X	X	scheduled
19-Jun-01	ns	X	scheduled
10-Jul-01	X	X	scheduled
24-Jul-01	ns	X	scheduled
7-Aug-01	X	X	scheduled
21-Aug-01	ns	X	scheduled
4-Sep-01	X	X	scheduled
18-Sep-01	ns	X	scheduled
23-Oct-01	X	X	scheduled

6-Nov-01	X	X	scheduled
20-Nov-01	ns	X	scheduled
4-Dec-01	X	X	scheduled
18-Dec-01	ns	X	scheduled
8-Jan-02	X	X	scheduled
22-Jan-02	X	X	scheduled
5-Feb-02	X	X	scheduled
19-Feb-02	X	X	scheduled
5-Mar-02	X	X	scheduled
19-Mar-02	X	X	scheduled
4-Apr-02	X	X	scheduled
15-Apr-02	X	X	scheduled
30-Apr-02	X	X	scheduled
21-May-02	X	X	scheduled
31-May-02	X	X	event
4-Jun-02	X	X	scheduled
10-Jun-02	X	X	event
18-Jun-02	X	X	scheduled
27-Jun-02	X	X	event
2-Jul-02	X	X	event
11-Jul-02	X	X	scheduled
23-Jul-02	X	X	scheduled
6-Aug-02	X	X	scheduled
12-Aug-02	X	X	event
20-Aug-02	X	X	scheduled
23-Aug-02	X	X	event
6-Sep-02	X	X	event
10-Sep-02	X	X	scheduled
24-Sep-02	X	X	scheduled
8-Oct-02	X	X	scheduled
22-Oct-02	X	X	scheduled
5-Nov-02	X	X	scheduled
18-Nov-02	X	X	scheduled
3-Dec-02	X	X	scheduled
12-Dec-02	X	X	event
17-Dec-02	X	X	scheduled
7-Jan-03	X	X	scheduled
21-Jan-03	X	X	scheduled
27-Jan-03	X	X	event
4-Feb-03	X	X	scheduled
18-Feb-03	X	X	scheduled
6-Mar-03	X	X	scheduled
18-Mar-03	X	X	scheduled
1-Apr-03	X	X	scheduled

scintillation vials (20-mL). A total of 54 scheduled sample sets were collected for nutrient analysis. One set was lost in transit to the analytical laboratory.

Beginning on 31-May-2002, collection of event samples from wells 5, 7, 8, 10, 12, 14 and 18 was initiated. Wells 5, 7, 8, 10, 12, and 14 were located in the middle of sweet corn plots and well 18 the furthest upgradient. Samples for both nutrient and pesticide residue analyses were obtained. In total, 9 event sample sets were collected. Their purpose was to determine if the rapid rise in the water table linked to large storm events (see Figure 8) was associated with increased pesticide and nutrient leaching. Instructions provided to field staff on when to collect event samples were:

a. Upon arrival at the laboratory, record daily rainfall from the FAWN weather station and water table elevations from the well maintained by the USGS for the prior day or days (if there was intervening weekend). As indicated, data are available on-line.
b. Whenever logistically possible, collect an event sample set when cumulative rainfall for the preceding 2 days was >2.5 cm and more than 2 days had elapsed since collection of the last event or scheduled samples.

There were two considerations in establishing these criteria. First, examination of the rainfall-water table elevation data record from prior years indicated that >2.5-cm of rain in a 2-day period would result in an observable rise in the water table. Second, SF_6-tracer studies (described in section 5.4 below) showed that groundwater velocity in the upper portion of the Biscayne aquifer below the plots was 3-9 m day^{-1}. Given the plot length (47 m) and well position ($\approx$ 17 m from the north end of plots) it was determined that sampling within 3 to 10 days following a large rainfall event may be required to capture peak concentrations of pesticide and nutrient residues in groundwater beneath the plots.

5. 3 Sample handling. Whenever scheduled or event samples were collected for pesticide residue analysis, they were packed in polystyrene foam boxes with freeze-paks and shipped the same day to the USDA-ARS Southeast Watershed Laboratory (SEWRL) in Tifton, Georgia. Overnight service was used. After receipt, samples were transferred to a laboratory refrigerator maintained at 4^{o}C.

Scheduled nutrient samples were also shipped on the date of collection using overnight service. Samples were delivered to the University of Florida Analytical Research Laboratory (UF-ARL) on the UF campus in Gainesville, FL. Beginning with samples collected on 28-January-2002, nutrient samples were syringed filtered using 0.45-*u* membrane filters prior to shipment. The decision to filter was based on Total Phosphorous (TP) results reported for samples collected during 2000 and 2001. Values varied widely and in some cases were exceptionally high. This appeared to be linked to a positive interference in the analysis caused by suspended solids (see section 6.2 below). After filtration, event samples collected for nutrient analysis were frozen and retained at TREC. They were shipped to the UF-ARL in 4 batches (1 batch every 2 weeks) beginning in May 2003.

5.4 Measurement of groundwater flow and direction. To determine hydraulic gradients that were needed for hydrogeologic characterization of the study site, water table elevation was continuously recorded in six monitoring wells starting on 29-Dec-2001. Well locations are shown in Figure 9 which shows a water table elevation contour map that was constructed using data collected on 16-April-02. The direction of groundwater flow inferred from the hydraulic gradient was S-SE. Water table elevation in wells 18D, H, G, and I are plotted for the period January-2002 to June 2003 in Figure 10. This Figure shows that the water table surface was consistently higher at well 18D. These show that gradients and the inferred groundwater flow direction was S-SE throughout the observation period. During the dry portion of the year, November-April, water table elevation generally decreased and gradients were stable. During the rainy season, May-October, when high rates of recharge were observed, and as a result, water table elevation increased and gradients were less stable. Although gradients were unstable during the rainy period, all data indicated that the predominant direction of groundwater flow was the same as that observed during the dry season.

Observation that the predominant direction of groundwater flow was S-SE was confirmed by two tracer tests using, sulfur hexafluoride (SF_6). The tests which were conducted in April 2002 and 2003 also yielded estimates of groundwater flow velocity. Values ranged from 3-9 m day^{-1}.

Figure 9. Water table elevation contours and direction of groundwater flow.

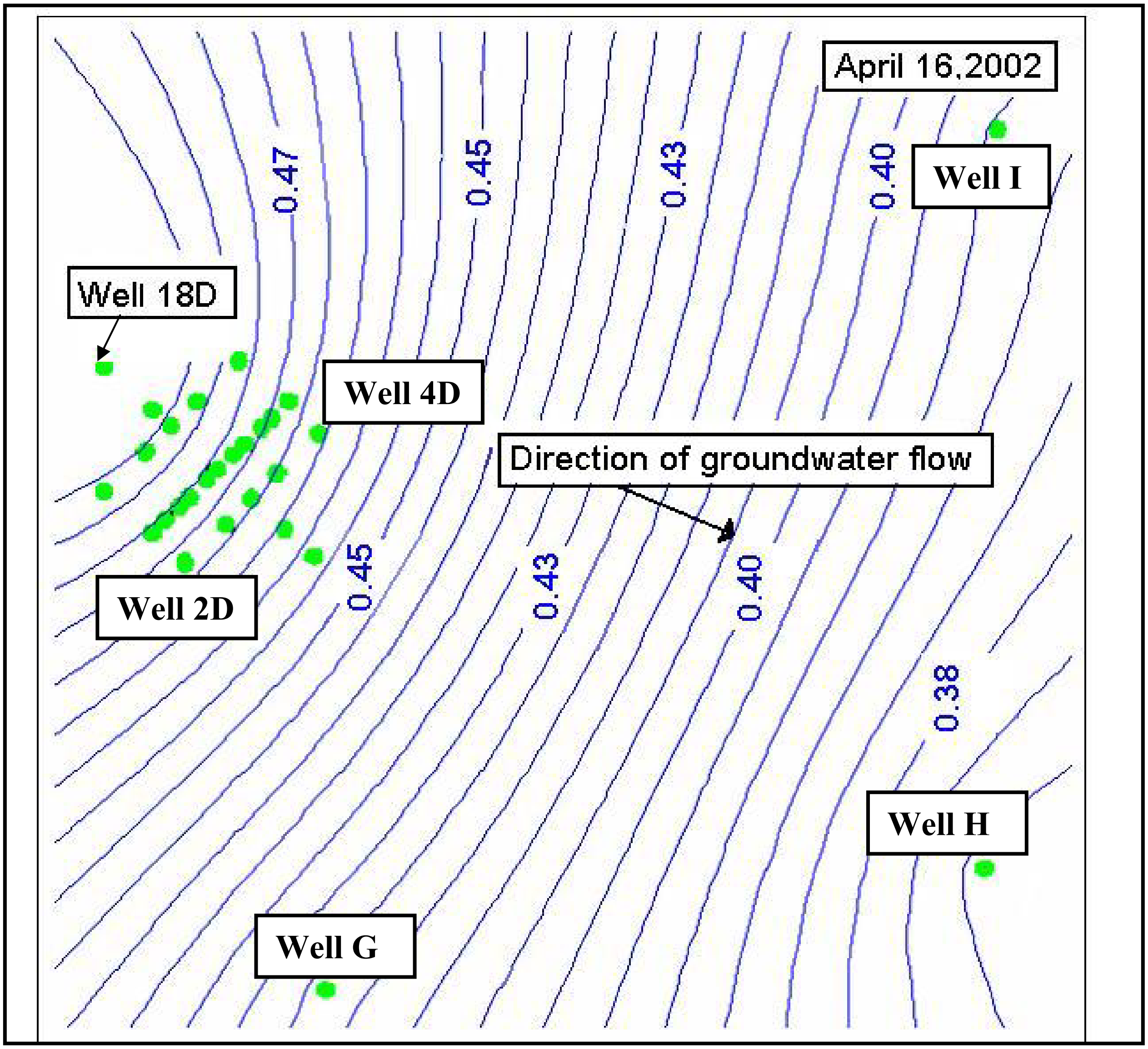
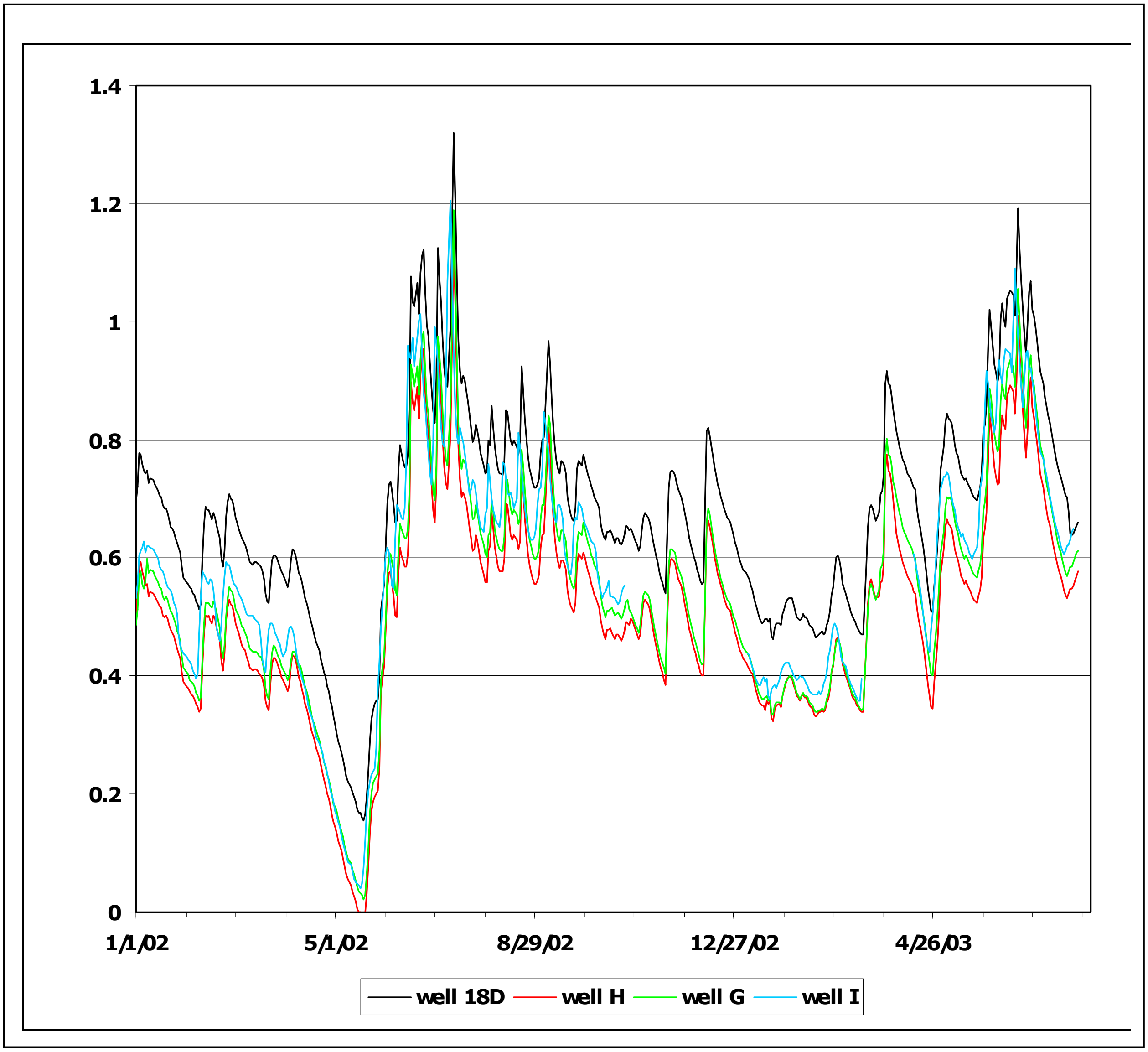


Figure 10. Water table elevation (m NGVD): January 2002 to June 2003.



6.0 WATER SAMPLE ANALYSIS

6.1 Pesticides. Within 2 days of receipt all samples were vacuum filtered. Filter media were 70-mm Whatman GF/F glass fiber filters (nominal pore size = 0.7-µm). After filtration pesticide residues were extracted using Oasis® HLB solid-phase extraction (SPE) extraction cartridges (Waters Inc., Milford, MA). SPE procedures were identical to those described by Potter et al. (2000). SPE cartridge eluents were combined and concentrated to 1-mL by evaporation under a directed stream of purified nitrogen gas and analyzed by High Performance Liquid Chromatography- Mass Spectrometry-Atmospheric Pressure Chemical Ionization-Mass Spectrometry (HPLC-APCI-MS). Four compounds were targeted in each analysis. Compounds were atrazine, and three atrazine degradates hydroxyatrazine (HA), desethylatrazine (DEA) and desisopropylatrazine (DIA). Structures are shown in Figure 11. Degradates targeted are widely distributed in aquatic environments and in many cases their concentration has been found to exceed the parent compound, atrazine (USEPA, 2003). DEA and DIA are also considered similar to atrazine in terms of human and ecological risks. The concentrations of atrazine and these two compounds are frequently summed when assessing human exposure risks (USEPA, 2003).

Quality assurance samples analyzed included field blanks, matrix spikes and field duplicates. The spikes were prepared from one of the 3 replicates obtained from monitoring well 7 beginning with the 9-January-2001 sample set. After filtration this sample was fortified with each compound at the rate of 1 ug L^{-1}. The duplicate pair consisted of the other well 7 replicate samples. In total data were obtained for 54 matrix spikes, 51 sets of duplicates and 75 field blanks during the study. None of the target analytes were detected in any of the field blanks. Method detection limits (MDL) were 0.005 ug L^{-1}. Matrix spike % recoveries and the relative percent deviation (%RPD) of duplicates are summarized in Table 7. These data indicate that recoveries were quantitative, averaging ≈100% for all compounds. The %RPDs, which averaged, 14 to 19%, indicated relatively high measurement precision. Regulatory programs often use %RPD=20 as an indicator of high data quality.

Figure 11. Structures of atrazine and the 3 degradates monitored.

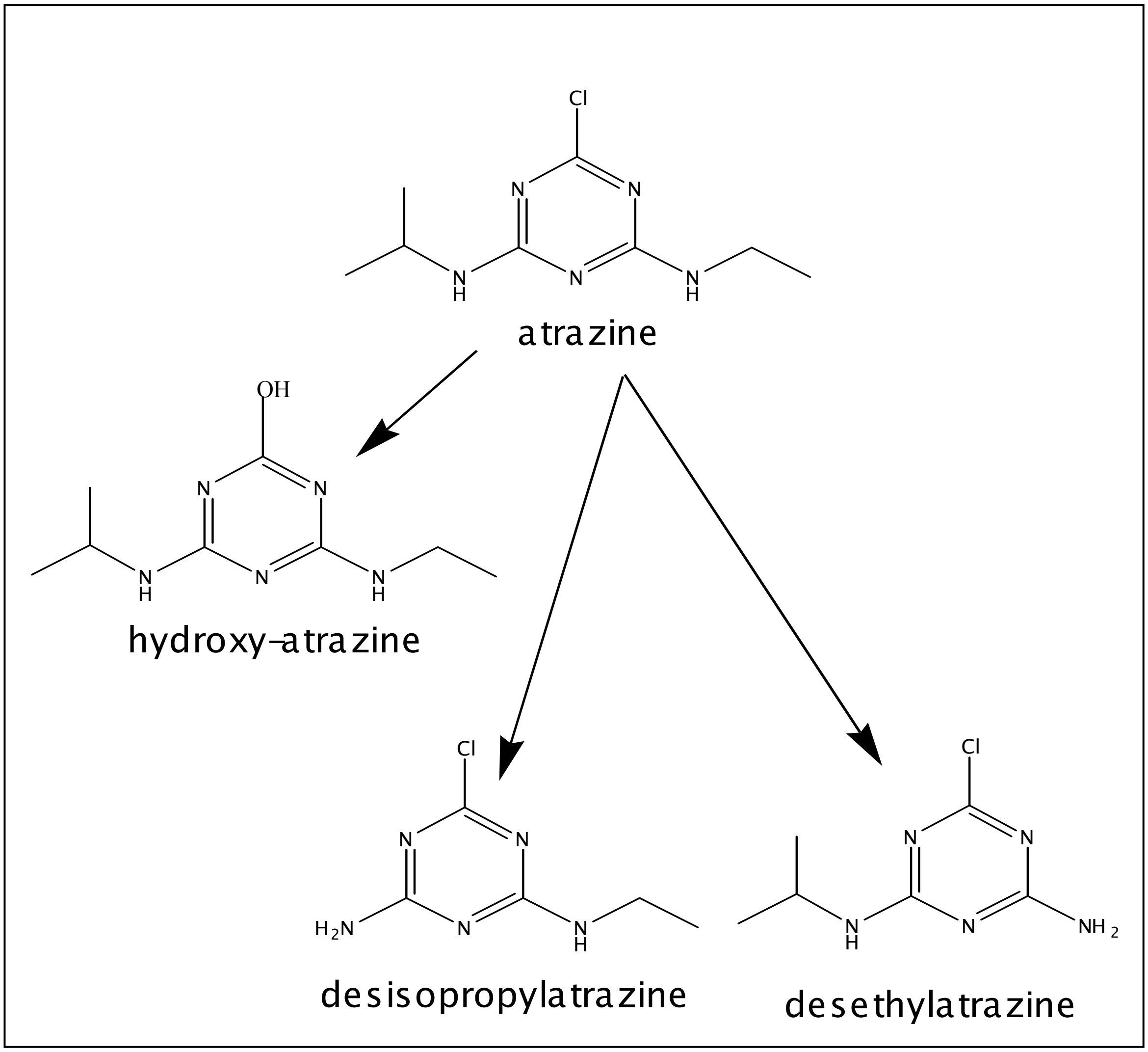


Table 7. Matrix spike % recovery and field duplicate % relative difference (%RPD) for DIA, HA, DEA and atrazine by SPE-HPLC-APCI-MS.

	% recovery (n=54)			
	DIA	HA	DEA	atrazine
average†	102 ± 9.4	104 ± 12	102 ± 12	99 ± 13
%RSD	9.2	12	11	13
maximum	130	140	130	130
minimum	82	75	72	63
	% RPD (n=51)			
average†	16 ± 13	19 ± 17	17 ±16	14 ± 14
%RSD	84	90	92	83
maximum	65	64	64	44
minimum	0.0	0.0	0.0	0.0

† ± 1 standard deviation.

6.2 Nutrient analysis. All analyses were performed at the UF-ARL. A description of the facility, including instrumentation, personnel, methods of analysis and quality assurance procedures are available on-line at http://arl.ifas.ufl.edu/. Parameters specified for each sample in each sample set were nitrate-nitrogen (NO_3-N), ammonia nitrogen (NH_4-N), Total Kjeldahl Nitrogen (TKN), total phosphorous (TP) and ortho-phosphate (o-PO_4).

During data analysis, a number of quality assurance problems were identified:

1). A relatively high % percentage of field blank results were reported to exceed method detection limit (MDL) TKN (31%), and o-PO_4 (18%). In one case, high o-PO_4 and TP levels in blanks was traced to a malfunction of the system used to prepare the distilled-deionized water used for field blanks. It is unknown to what extent this malfunction are other contamination sources affected other blank or groundwater sample results.

2). Comparison o-PO_4 and TP values showed that in 70% of all samples the o-PO_4 concentration reported was greater than the TP value. By definition TP should be $\geq$ o-PO_4 in all cases. This led us to question about the quality of o-PO_4 and TP measurements. When contacted, ARL staff suggested that the source of the problem was a silicate inference in o-PO_4 analyses. This was supported by published studies which showed that silicate positively interferes in low-level o-PO_4 analysis and that the interference is removed during sample digestion for TP analysis (Zhang et al., 1999). Thus, the presence of relatively high levels of dissolved silicate in groundwater samples may explain results. Studies conducted at UF-ARL appear to have confirmed this (Kennelley and Mylavarapu, 2002).

3.) Anomalously high and highly variable TP levels reported for samples collected in 2000 and 2001 suggested that an inference may have comprised the quality of many TP measurements. TP concentration in >35% of all samples exceeded 100 ug L^{-1} and values > 500 ug L^{-1} were reported for some upgradient well samples. The expected range in TP concentration in SDB groundwater was indicated by a survey conducted by the USGS in 1998 (USGS, 2004). Twenty-four shallow wells were sampled and analyzed including some wells within fields in vegetable crop production. Total dissolved phosphorus concentration was <1.0-68 ug L^{-1}. A visit to ARL in July 2001 to consult on this problem suggested that suspended particulate matter in groundwater samples was the source of instability and abnormally high TP levels that were reported. High turbidity was observed in some samples as they flowed through the ARL TP autoanalyzer system. The particles likely inflated TP concentrations by contributing to light extinction in the system's spectrophotometer. Filtration was initiated in an effort to improve the quality of TP measurements. Starting with the 8-January-2002 sample set, all samples were membrane filtered (0.45 *u*) prior to shipment. Comparison of average TP values collected prior to and after filtration supported the conclusion that sediments had contributed to the elevated TP levels. TP in unfiltered samples collected and analyzed in 2000-2001, averaged 133 ug L^{-1}. The average of all subsequent samples was 6 ug L^{-1}.

In sum there were a number of quality control problems with nutrient analysis results most notably with TKN, o-PO4 and TP analyses. Impact on the quality of data reported for groundwater samples is unknown and unspecified. Thus, these parameters are excluded from further discussion in the report.

7.0 RESULTS AND DISCUSSION

7.1 Crop yield and quality. Table 8 provides summary statistics for crops harvested in 2001, 2002 and 2003 (no data were collected for the crop harvested in 2000). No statistically significant differences between treatments, cover versus no-cover, were observed for any of the yield or quality parameters measured; however, there was a trend to higher yield on cover crop plots.

Although significant treatment differences were not observed, yield and quality on both cover and no-cover plots were generally high when compared to SDB grower averages. Typical grower yields in SDB are 740-1100 cartons per hectare (Li et al., 1997). Yields during our study were 1100-2200 cartons per hectare (Table 8). Thus it can be safely concluded that use of Sunn Hemp as a summer cover crop did not reduce or otherwise negatively impact yield or quality. BMPs are by definition practices which should increase or maintain yields while providing environmental benefits (Simonne et al., 2003). The study results confirmed that the first condition of this definition was met.

7.2 Pesticide Analysis Results. Atrazine, DEA, DIA and HA were detected in all samples. The MDL was 0.005 ug L^{-1}. Summary statistics are compiled by well location (upgradient, cover and no-cover) in Table 9 and the average of the sum of atrazine plus degradates concentrations (ATSUM) is plotted by sample collection data in Figure 12. Figure 13 shows the DIA, HA, DEA, and atrazine concentrations in canal samples. All data sets exhibited strong positive skewness, 0.4-6.1, (Table 9) thus emphasis is placed on the geometric mean as an estimate of central tendency in the following discussion.

Comparison of geometric means suggested that DIA, DEA, atrazine, and ATSUM concentrations and DEA to atrazine molar ratios (DAR) associated with the no-cover crop wells were all greater when compared to cover crop plot wells. DEA levels showed the greatest difference. The no-cover crop DEA geometric mean was ≈2X greater than the corresponding cover crop value. This difference was reflected in the DAR. The no-cover crop plot well geometric mean was 3 whereas a value of 2 was obtained with cover crop plot well samples.

Table 8: Sweet corn yield summary: 2000-2003[&].

	2000-2001		2001-2002		2002-2003	
	cover n=3	no-cover n=3	cover n=3	no-cover n=3	cover n=3	no-cover n=3
# marketable ears[†]	108 ± 29	97 ± 41	100 ± 15	89 ± 17	184 ± 2.3	142 ± 29
# culled ears[†]	78 ± 28	91 ± 19	105 ± 29	115 ± 27	144 ± 57	138 ± 45
% ears marketable[†]	58 ± 8.5	50 ± 15	49 ± 16	44 ± 16	56 ± 17	51 ± 19
length per marketable ear (cm)	18 ± 0.3	18 ± 0.3	17 ± 0.3	17 ± 0.3	18 ± 0.6	17 ± 0.4
width per marketable ear (cm)	4.6 ± 0.1	4.7 ± 0.2	4.7 ± 0.1	4.8 ± 0.03	5.0 ± 0.2	4.8 ± 0.1
weight per marketable ear (g)[†]	260 ± 40	270 ± 40	280 ± 10	290 ± 30	260 ± 20	250 ± 20
1000 * estimated yield (cartons/ha)[‡]	1.3 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.1 ± 0.1	2.2 ± 0.1	1.7 ± 0.3

[&] Crop year 1999-2000 yields not recorded.[†] 2 15-m rows per plot were harvested; [‡] normal range of Miami-Dade county grower yield is 740-1110 cartons per ha (Li et al., 1997)

DAR is often used to evaluate point source versus non-point source contamination of groundwater by atrazine. Adams and Thurman (1991), who first proposed the concept, associated low DAR values (<1) with point source and high values (>1) with non-point source contamination. In the context our study the relatively high DAR values in both no-cover and cover crop well samples indicated that atrazine was extensively degraded in soil before leaching occurred. The higher mean DAR observed with no-cover crop well samples also suggested that there was more extensive degradation in no-cover crop when compared to the cover crop plot soil. An alternate explanation is that DAR differences were due to more extensive total degradation in cover crop plot soils as reflected by the lower ATSUM values for cover crop

Table 9. Summary statistics: DEA to atrazine molar ratio (DAR) and atrazine, DIA, HA, DEA and ATSUM concentration in water samples.

	DIA (ng L^{-1})	HA (ng L^{-1})	DEA (ng L^{-1})	atrazine (ng L^{-1})	ATSUM (nmol L^{-1})	DAR
cover wells						
range	<5-190	22-170	<5-1200	9-2200	0.4-17	0.1-7.6
avg±std[‡]	31 ± 28	66 ± 24	190 ± 190	110 ± 200	2.1 ± 1.8	2.8 ± 1.9
geomean	21	61[†]	117	68	1.6	2.0
skewness	2.4	1.2	2.0	6.1	3.6	0.4
# >MCL[†]	0	0	0	0	1	-
no-cover wells						
range	<5-250	<5-130	<5-2800	5-1100	0.4-18	0.1-20
avg±std	48 ± 37	58 ± 20	340 ± 380	110 ± 200	2.9 ± 2.5	4.4 ± 3.7
geomean	37[†]	54	205[†]	80[†]	2.3[†]	3.0[†]
skewness	2.5	0.9	4.0	4.6	3.7	1.7
# >MCL	0	0	0	0	4	-
upgradient wells						
range	<5-44	<5-150	<5-56	<5-150	0.04-1.2	0.1-2.5
avg±std	4.8 ± 5.2	58 ± 21	8.7 ± 5.6	28 ± 21	0.5 ± 0.2	0.5 ± 0.3
geomean	3.5	53	7.2	22	0.5	0.4
skewness	3.4	1.2	3.5	2.3	0.7	2.3
# >MCL	0	0	0	0	0	-
canal						
range	<5-34	25-230	<5-36	<5-233	0.3-2.2	<0.1-3.2
avg±std	6.7 ± 4.9	90 ± 39	9.6 ± 6.0	28 ± 33	0.7 ± 0.3	0.6 ± 0.5
geomean	5.5	83	7.9	20	0.6	0.5
skewness	2.7	1.4	1.7	4.2	2.2	1.0
# >MCL	0	0	0	0	0	-

[‡] “avg±std” = average ± standard deviation; geomean = geometric mean; significantly greater than corresponding cover or no-cover value ($P<0.02$); [†]# MCL= number of samples with concentration > atrazine drinking water maximum contaminant level.

Figure 12. Average ATSUM concentration in monitoring well samples.

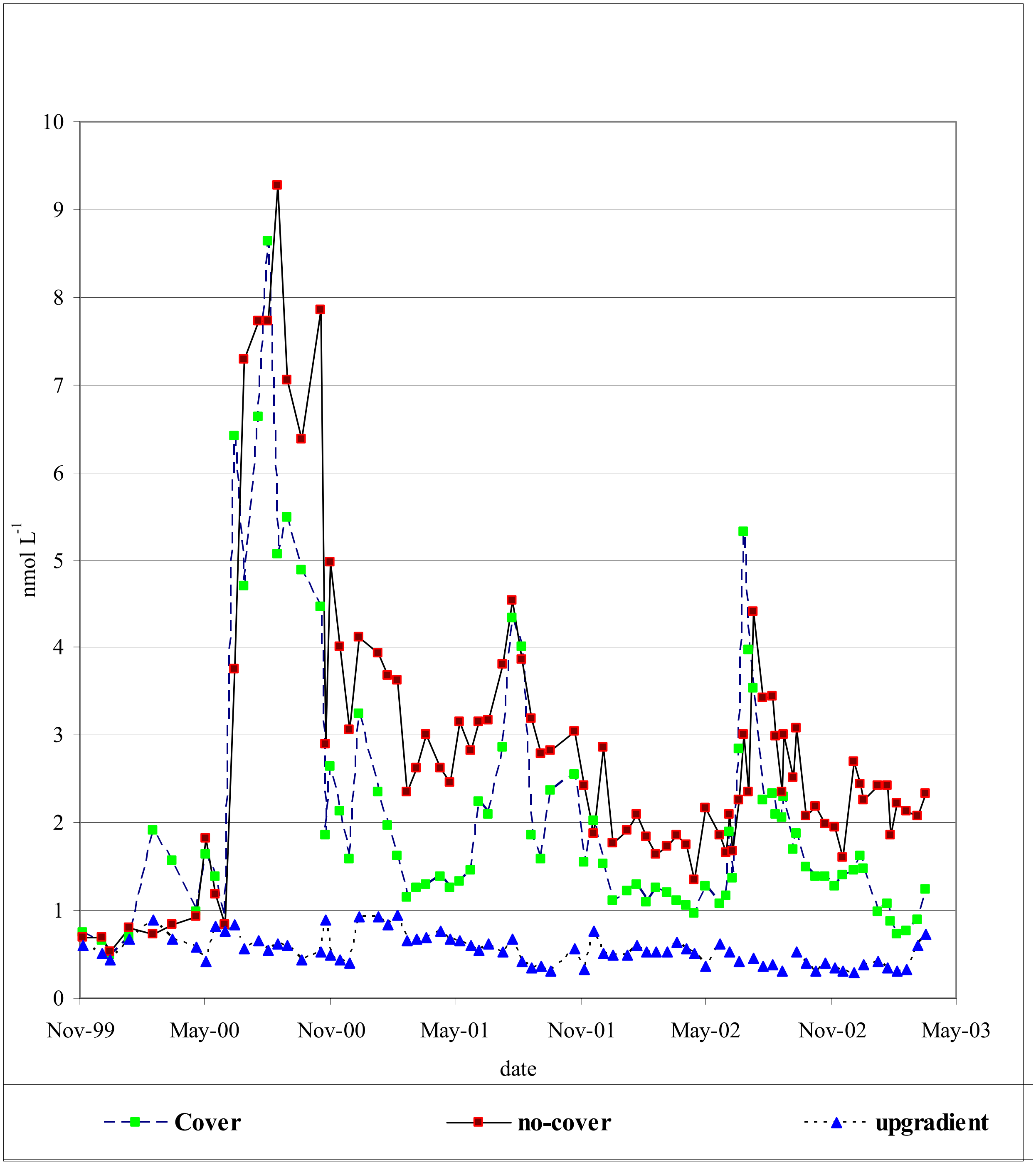
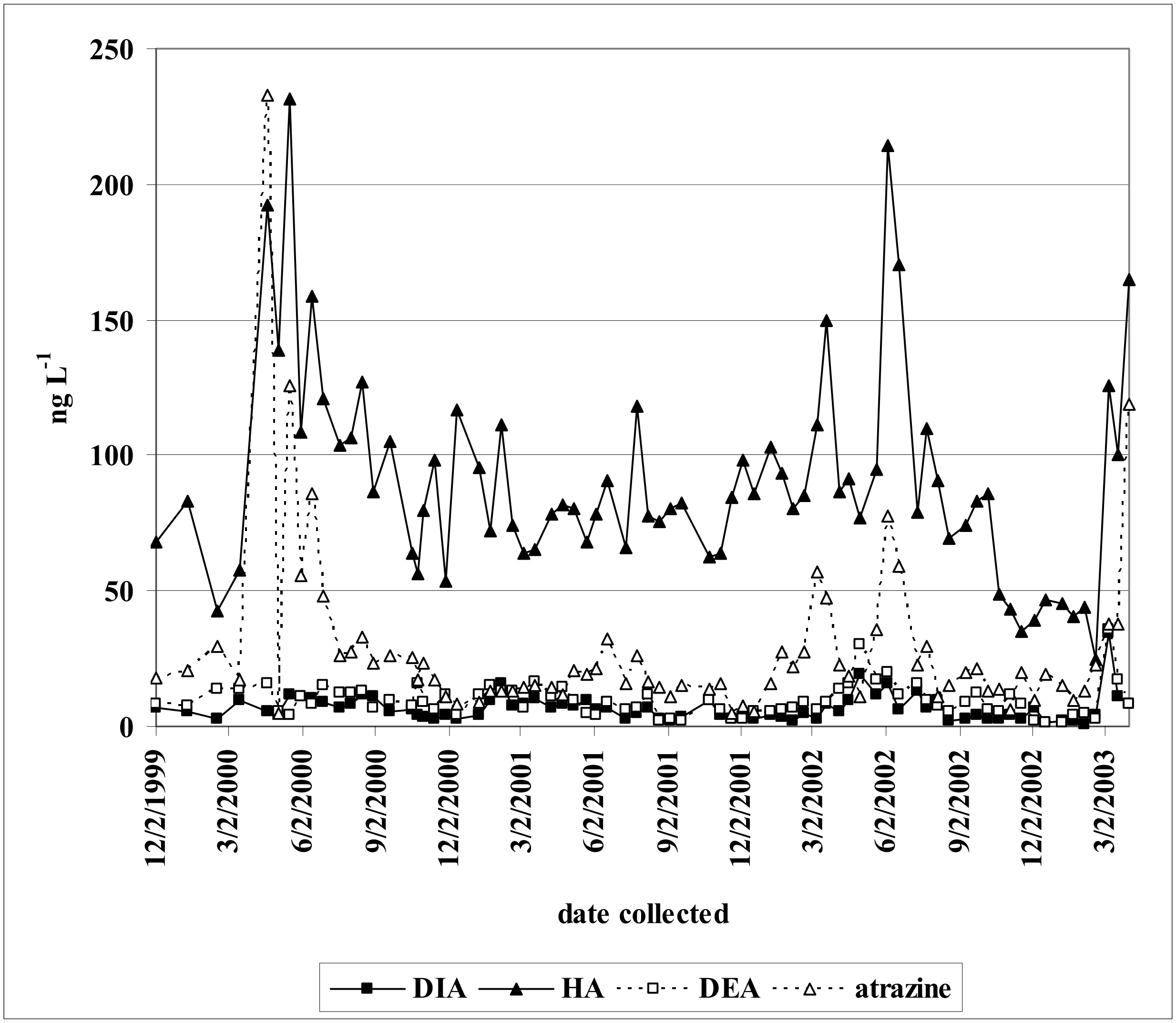


Figure 13. Atrazine, DEA, DIA and HA concentration in C-103 canal samples: November 1999 to April 2003.



plot well samples. More of the DEA that was formed in cover crop plot soil was likely degraded to other products and or mineralized before it could be leached.

HA trends were opposite to the other compounds. Its geometric mean concentration was greater in samples collected from cover crop plot wells. HA is considered less toxic than DEA, DIA and atrazine (USEPA, 2003). Thus factors which promote HA formation from atrazine instead of DEA or DIA may translate to water quality risk reduction.

The highest HA levels were observed in canal samples (Figure 13; Table 9). HA accounted for 60-80 % of the ATSUM. Since the canal is hydraulically upgradient of the research plots, it is unlikely that the higher HA concentration in canal samples was related to atrazine use during the study. The HA observed was presumably connected to its introduction into the canal system at upstream locations. Lerch et al. (1998) reported that HA predominated in small streams in the Midwestern USA under preplant (before application) conditions. This behavior was attributed HA's greater persistence in soils and sediments when compared to atrazine, DEA and DIA. HA's relatively high resistance to degradation may have allowed it to persist during transport in surface drainage from outside SDB.

HA also predominated in hydraulically upgradient wells. This was attributed to the proximity of these wells to the canal and hydraulic connection that exists between the canal and shallow groundwater in the area. The distribution of degradates and residue levels detected in the upgradient wells mirrored canal samples.

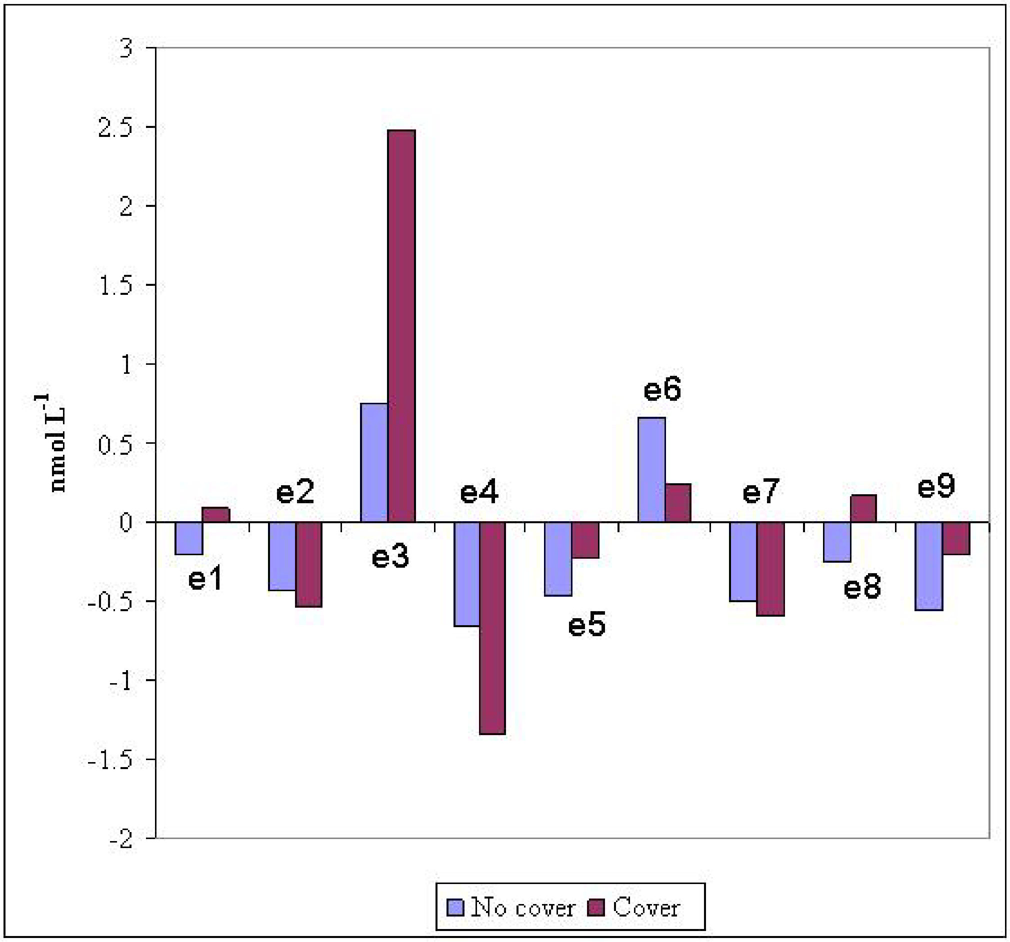
Another observation regarding the Table 9 results was that peak concentrations were relatively low even in samples collected in wells located in the middle of atrazine treated plots. The maximum ATSUM concentration in no-cover and cover crop plot wells was 17 and 18 nmol L^{-1}, respectively. This was only slightly above atrazine's drinking water maximum contaminant level for atrazine alone, which is 14 nmol L^{-1} (USEPA, 2003). The ATSUM concentration exceeded the MCL in only 4 samples collected from no-cover crop and 1 from cover crop monitoring wells. In no case did concentrations of atrazine, DEA, DIA or HA considered individually exceed the MCL.

These results were surprising in light of what appeared to be worst case leaching conditions at the study site, i.e. shallow groundwater and highly porous soil with low pesticide adsorption capacity. An explanation of why higher levels of atrazine and or degradates was not observed is likely linked to distribution of SDB rainfall and cropping practices. As indicated in Figure 8, during the study period most of the rainfall occurred between May to October. This is a typical pattern for the region. The corn crops in this study, as are most SDB vegetable crops, were produced during the dry season which generally lasts from November to April. Because rainfall is low during this period, leaching rates are low.

These trends are reflected in Figure 12. In all years, peak ATSUM concentration in groundwater was not observed until May. This was after the sweet corn was harvested and the rainy season had begun. We hypothesize that during the approximately 4 months between the time of atrazine application and the beginning of the rainy season a large fraction of the atrazine applied preplant (November) was either mineralized, degraded to forms not tested for, or otherwise dissipated. Thus only small amounts remained in the soil and were available for leaching when the rainy season began. The net result was that levels of atrazine and degradates in groundwater were generally low regardless of management practices.

A counter to this was that the scheduled sample collection program, which was biweekly through most of the study, was not intensive enough to capture leaching events. Thus, leaching may have been underestimated. The potential for this to occur was assessed by implementing the event sampling program (described in section 5.3 above). From May 2002 to January 2003, 9 event samples were collected. A plot of the difference in the average ATSUM concentration in event samples and prior scheduled samples is shown in Figure 14. In this plot, a positive value indicates that the event sample concentration was higher and negative value that the scheduled sample concentration was higher. It follows that a positive value would identify a leaching event. With only two exceptions, the differences observed were negative. Thus, we concluded that our biweekly sampling regime did effectively capture leaching events at the study site. This conclusion was reinforced by a similar treatment of NO_3-N concentration results (see section 7.3).

Figure 14. Difference in ATSUM concentration between event and prior scheduled samples.



To assess overall treatment (cover versus no-cover) related differences in leaching, the areas under-the-curve in plots of ATSUM and the sum of chlorotriazines (CLTRI) concentration versus date of sample collection were determined for each of the no-cover crop (7,8,14) cover crop (5,10,12) and upgradient wells (15,16,17,18). The "trapezoid rule" was used for calculations (Beyer, 1978). The concept is illustrated in Figure 15. Areas under-the-curve for average ATSUM concentrations for each well group are shaded. Because CLTRI results mirrored ATSUM only ATSUM results are discussed below.

Results, which are summarized in Table 10, were normalized by dividing the average areas for all wells in a given well group by the average for the no-cover crop wells and as indicated computations were made for two observation periods, pre-BMP and post-BMP. The pre-BMP period included all samples collected from the start of the study (5-November 1999) up to and including samples collected on 19-September-2000. The next collection date (17-October-2000) marked the beginning of the post-BMP period. In between these dates, the 1st cover crop was mowed and turned into the soil, atrazine was applied, and the second sweet corn planted. The post-BMP period continued to 4-April-2003 when the last water quality samples were collected.

During the pre-BMP period the relative areas shown in Table 10 for cover and no-cover crop well samples were nearly equal thus it can be concluded that nearly equal amounts of atrazine and degradates that were formed leached below the root zone on all plots. This was confirmed by hypothesis testing in which areas under-the-curves that were associated with the no-cover and cover crop treatments were compared by t-tests. Differences in mean areas were small (≈ 11%) and not significant ($P=0.81$). The response described is reflected in the large peaks shown in the ATSUM concentration plots in Figure 12. Peaks in no-cover and cover crop well plots during the pre-BMP period were approximately equal in size.

Figure 12 also shows that there was a trend toward lower ATSUM concentration in groundwater samples collected from both no-cover crop and cover crop plot wells in the post-BMP period. A likely explanation is that the atrazine degradation rate in soil at the study site increased after the 1st application due to stimulation of atrazine degrading microorganisms. This

Figure 15. Diagram showing areas under-the-curve for average ATSUM concentration in cover crop and no-cover crop plot and upgradient well samples.

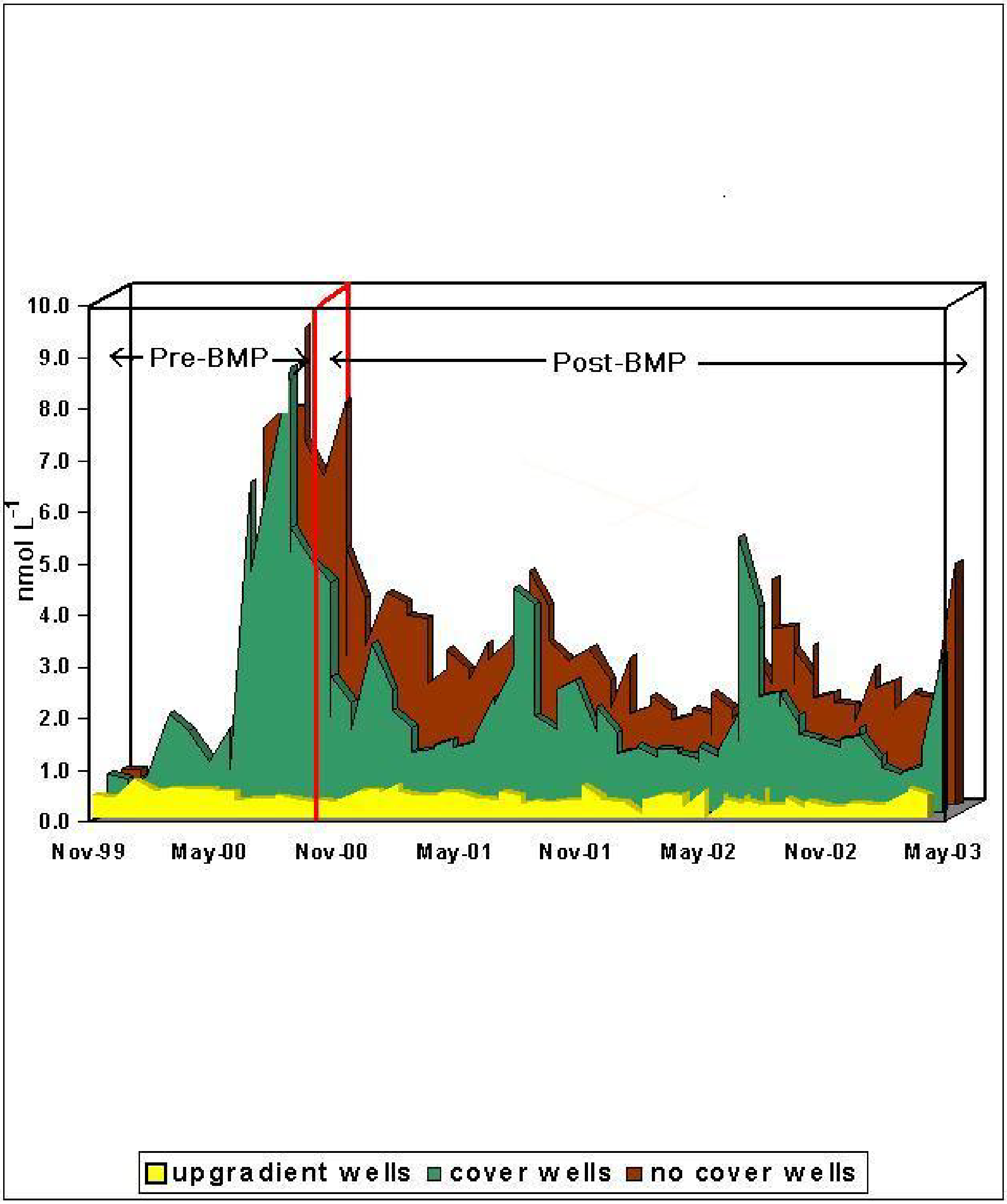


Table 10.Normalized average area (± 1 standard deviation) under-the-curve for ATSUM and CLTRI plots of concentration and sample collection dates for no-cover crop, cover crop and upgradient well samples.[†, ‡]

	ATSUM		CLTRI	
	Pre-BMP	Post-BMP	Pre-BMP	Post-BMP
upgradient wells	0.19 ± 0.03	0.18 ± 0.04	0.10 ± 0.02	0.08± 0.02
cover crop plot wells	0.89 ± 0.11	0.66 ±0.13	0.88 ± 0.14	0.60 ± 0.16
no-cover crop plot wells	1.00 ± 0.78	1.00 ± 0.25	1.00 ±0.85	1.00 ± 0.27
P[§] (cover vs. no-cover)	0.81	0.10	0.82	0.09
P (cover vs. upgradient)	<0.01	<0.01	<0.01	<0.01
P (no-cover vs. upgradient)	0.14	<0.01	0.14	<0.01

[†] units for areas are nmol-day L^{-1}; [‡]data normalized by dividing all values by the no-cover crop wells area; [§]probability of a significant difference based on a t-test.

type of atrazine behavior has been observed in many settings (Vanderheyden et al., 1997; Abdelhafid et al., 2000).

While ATSUM concentrations trended lower on all plots in the post-BMP period, comparison of the cover crop and no-cover crop treatments showed that significantly (P=0.10) lower leaching of combined atrazine residues was associated with use of the cover crop. The average normalized area under the ATSUM concentration-date of sample collection curves for cover crop plots was 0.6 (Table 10). This translates to 40% less total atrazine leaching on these plots.

Several factors likely contributed to atrazine leaching reduction by the cover crop. When it was tilled into the soil a large amount of fresh organic matter was added. This presumably increased soil metabolic activity. In turn, higher rates of atrazine metabolism may have resulted. This is consistent with observations by Bottomley et al (1999) that winter cover crops enhanced the rate of soil mineralization of another herbicide, 2,4-D. Higher degradation rates would contribute to lower the amounts of herbicides remaining available for leaching. The plant residues may also have increased atrazine adsorption by the soil. Consequently less was available for leaching and more was retained in the soil where it could be degraded.

Other possible cover crop impacts may have been due to changes in soil water relations. The plant residues turned into the soil would tend to increase soil water holding capacity and reduce leaching. In addition, it is likely that during the time period when the cover crop was actively growing, evapo-transpiration from the plant canopy was expected to remove water from the soil and reduce leaching associated with subsequent rainfall events.

In sum, the study demonstrated relatively low atrazine and degradates leaching rates with or without use of a cover crop. The maximum enrichment levels in ground water beneath cropped plots treated with atrazine was only 5X above background (upgradient) and only a small faction (<1%) of all samples had combined atrazine residues which exceeded the atrazine MCL. Results are showed that while atrazine leaching rates observed were generally low, use of the cover crop reduced leaching further. The leaching reduction was ≈40%.

7.3 Nutrient analysis results. All samples contained detectable NO_3-N. Data are summarized in Table 11 and in Figure 16. Samples were tested for NH_4-N but it was not detected at a laboratory reported method detection limit of 0.3 mg L^{-1}. No further discussion of NH_4-N results is provided. As observed with the pesticide data, NO_3-N data were positively skewed (Table 11). Thus the discussion focuses on comparing geometric means. They were 4.2, 4.4 and 4.9 mg L^{-1} for cover, upgradient and no-cover well samples, respectively. The mean for no-cover crop plot wells indicated some NO_3-N enrichment in groundwater below these plots relative to background (upgradient wells) and the cover crop plots. The very small difference between the cover crop and upgradient well sample geometric means suggested that use of nitrogen containing fertilizers on the cover crop plots had no impact on NO_3-N levels in groundwater. Failure to observe enrichment in this case and identification of only slightly (≈20%) higher mean NO_3-N in no-cover crop plot well samples was likely due to the relatively high NO_3-N concentration in upgradient wells. Values ranged from 0.5 to 11 mg L^{-1} and as indicated the geometric mean was 4.4 mg L^{-1}. High NO_3-N levels were likely due to NO_3-N leaching from a large (≈16-ha) field immediately upgradient that was maintained in green bean production. Upgradient well NO_3-N concentrations were within the range reported for samples

Table 11. Summary statistics: NO_3-N concentration in monitoring well samples.

	NO_3-N ($mg\ L^{-1}$)
cover wells	
range	1.0-17
avg±std[‡]	4.8 ± 2.8
geomean	4.2
skewness	1.4
[†]# >MCL	6
no-cover wells	
range	1.4-14
avg±std	5.3 ± 2.2
geomean	4.9[†]
skewness	1.0
[†]# >MCL	3
upgradient wells	
range	0.5-11
avg±std	4.5 ± 1.7
geomean	4.4
skewness	0.5
[†]# >MCL	0

[‡] "avg±std" = average ± standard deviation; geomean = geometric mean; significantly greater than corresponding cover or no-cover value ($P<0.02$) [†]# >MCL= number of samples with concentration > atrazine drinking water maximum contaminant level.

collected beneath other SDB fields in vegetable crop production (USGS, 2004). Data collected during a USGS study indicated that NO_3-N levels in the upper portion of the Biscayne aquifer in SDB areas without urban or agricultural impacts was <0.05 $mg\ L^{-1}$ (USGS, 2004).

Finally, evaluation of NO_3-N results using the area under-the-curve approach described in discussion of atrazine data above did not did not reveal significant differences ($P=0.1$) for either the pre-BMP or post-BMP periods (Table 12). Comparison of event and scheduled sample NO_3-N results in the same way that atrazine results for these samples was handled also showed that

Figure 16. NO_3-N concentration in monitoring well samples.

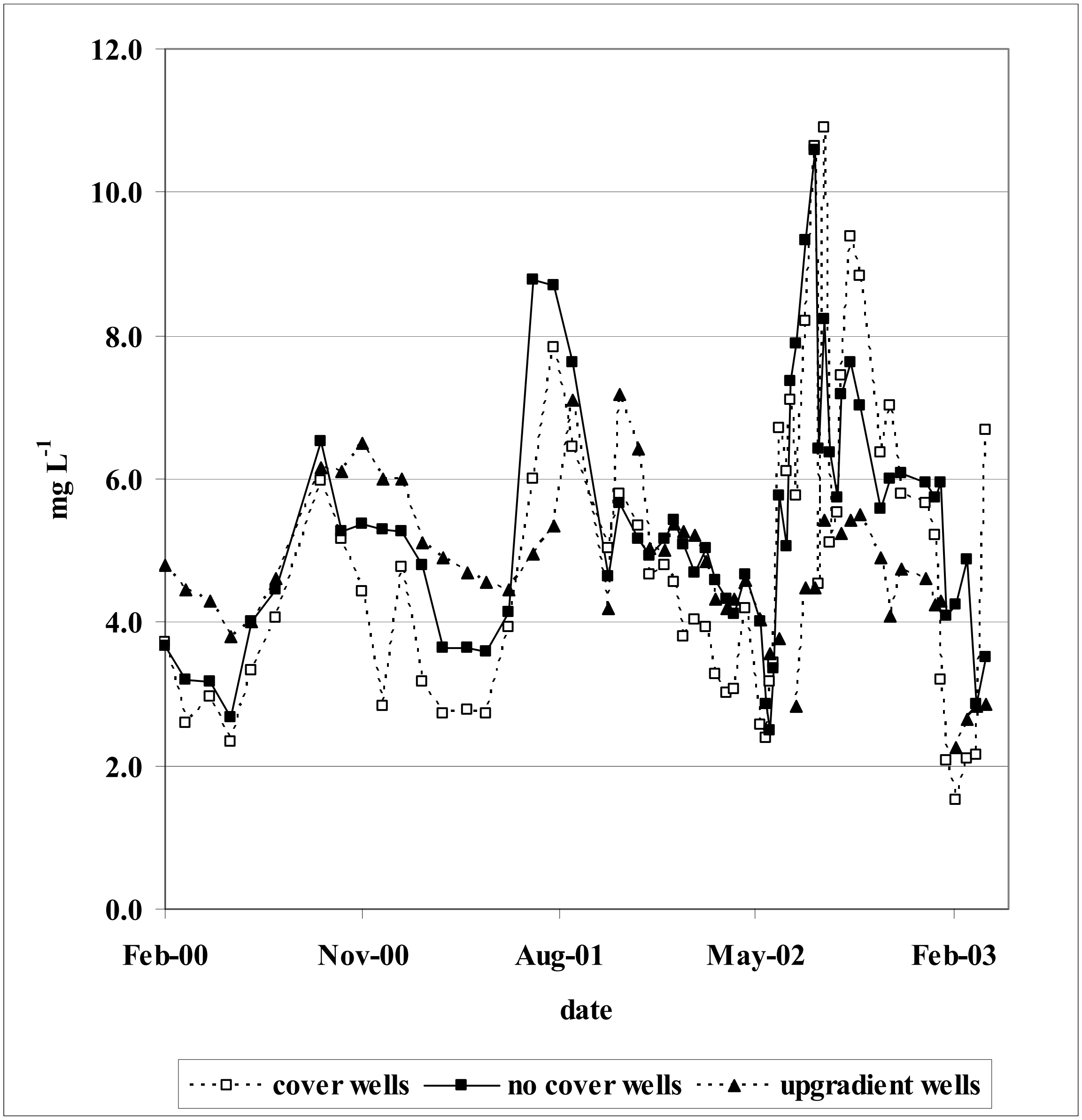


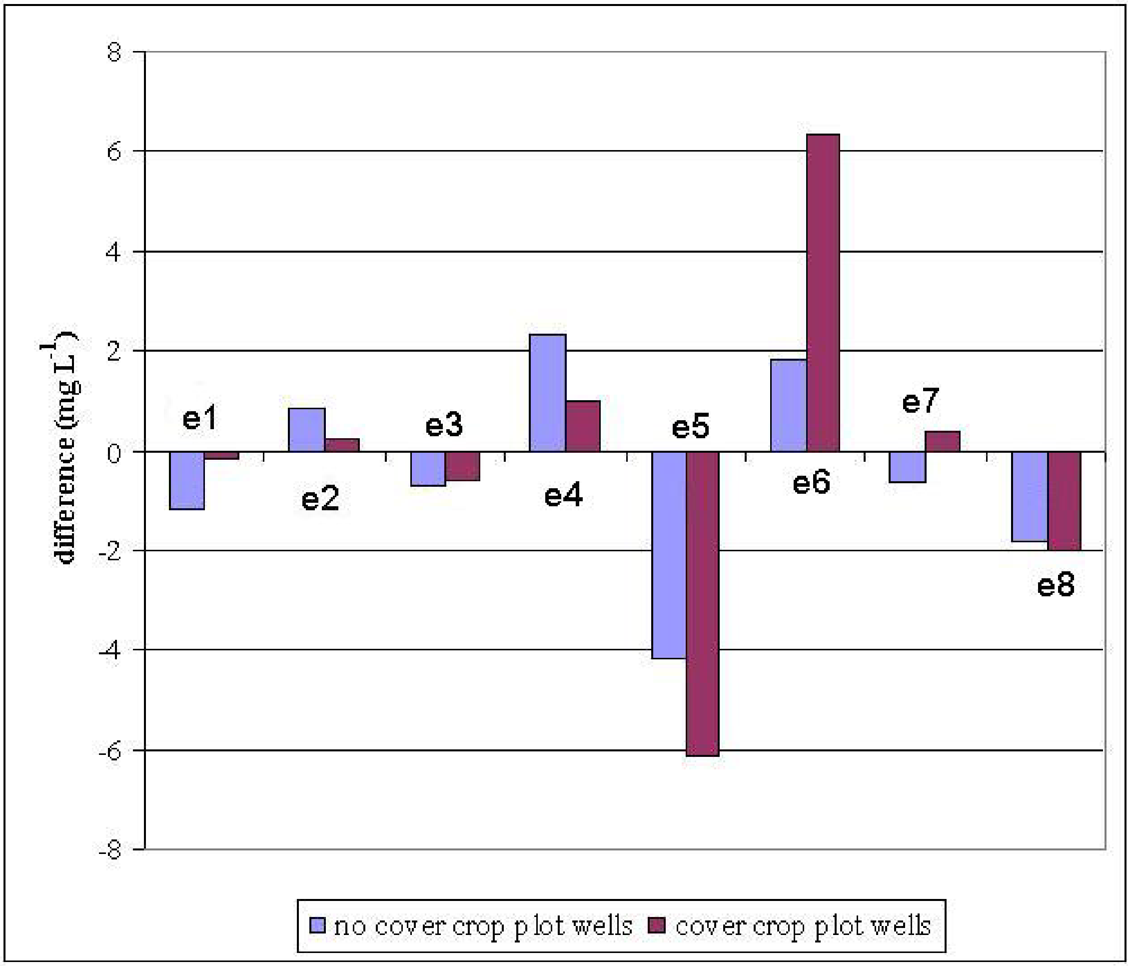
Table 12. Normalized average area (± 1 standard deviation) under-the-curve for plots of nitrate nitrogen (NO_3-N) concentration and sample collection dates for no-cover crop, cover crop and upgradient wells.[†, ‡]

	observation period	
	Pre-BMP	Post-BMP
no-cover crop plots wells	1.00 ± 0.19	1.00 ± 0.21
cover crop plot wells	0.90 ± 0.15	0.88 ± 0.10
upgradient wells	1.06 ± 0.16	0.84 ± 0.20
probability[§] (cover vs. nocover)	0.52	0.42
probability (cover vs upgradient)	0.27	0.42
probability (no-cover vs. upgradient)	0.68	0.39

[†] Units for areas are nmol-day L^{-1}; [‡]data normalized by dividing all values by the no-cover crop wells area; [§]probability of a significant difference based on t-test.

that in the majority of cases, the difference between the event and prior scheduled sample NO_3-N concentrations was negative (Figure 17). Thus, we concluded that the sampling regime effectively NO_3-N leaching as well. It appears that because, background NO_3-N levels were high in groundwater, detection of a difference between no-cover and cover treatments may have been beyond limits of conditions at the study site.

Figure17. Difference in NO_3-N concentration between event and prior scheduled samples.



8.0 LITERATURE CITED

Abdelhafid, R.; Houot, S.; Barriuso, E. 2000. Dependence of atrazine degradation on C and N availability in adapted and non-adapted soils. *Soil Biol. Biochem*. 32:389-401.

Adams, C.D. Thurman, E.M. 1991. Formation and transport of desethylatrazine in the soil and vadose zone. *J. Environ. Qual*. 20:540-546.

Alperts, M. 1999. Replumbing the Everglades. *Scientific American*. August 1999 issue.

Anderson, D.L.; Rosendahl, P.C. 1998. Development and management of land/water resources: the Everglades, agriculture and south Florida. *Jour. Am. Water Res. Assoc*. 34, 235-249.

Beyer, W.H. 1978. *CRC Standard Mathematical Tables*. CRC Press Inc., Boca Raton, FL.

Bottomley, P.J.; Sawyer, T.E.; Boersma, L.; Dick, R.P.; Hemphill, D.S. 1999. Winter cover crop enhances 2, 4-D mineralization potential of surface and subsurface soil. Soil *Biol. Biochem*. 31:849-857.

Childers, D.L.; Doren, R.F.; Jones, R.; Noe, G.B.; Rugge, M.; Scinto, L.J. 2003. Decadal change in vegetation and soil phosphorous patterns across the Everglades landscape. *J. Environ. Qual*. 32:344-362.

Degner, R.L.; Stevens T.J.; Mulkey, D.; Hodges, A. 2001. *Economic Impact of Agriculture and Agribusiness in Miami-Dade County, Florida: A Summary*. EDIS document FE308, Department of Food and Resource Economics, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, September 2001. http://edis.ifas.ufl.edu/FE308 (verified March 14, 2004).

Degner, R.L.; Stevens, T.J.; Morgan, K.L. 2002.*Miami-Dade County Agricultural Land Retention Study: Summary and Recommendations.* Florida Industry Report 02-02. Florida Agricultural Market Research Center, Institute of Food and Agricultural Sciences, University of Florida, April 2002. http://agmarketing.ifas.ufl.edu/dlfiles%5CSummary.pdf (verified March 14, 2004).

ES&E, 1996. *Contamination Assessment report Addendum for the Tropical Research and Education Center, Homestead, FL*. Report prepared for the Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL by Environmental Science & Engineering, Inc., Gainesville, FL.

Fish, J.E.; Stewart, M., 1991. *Hydrogeology of the Surficial Aquifer System, Dade County, Florida.* U.S. Geological Survey Water-Resources Investigations Report 90-4108, U.S. Geological Survey, Denver, CO., 56 pp. available on-line at http://sofia.usgs.gov/publications/wri/90-4108/wri904108.pdf. (verified March 14, 2004).

Genereux, D.; Slater, E. 1999. Water exchange between canals and surrounding aquifer and wetlands in the southern Everglades, USA. *J. Hydro.* 219:153-168.

Graham, W.D.; Campbell, K.L.; Mossa, J.; Motz, L.H.; Rao, P.S.C.; Wise, W.R.; Genereux, D. 1997. *Water management issues affecting the C-111 basin, Dade County, Florida: hydrologic sciences task force initial assessment report*, CNR-1997-1002. Univ. Fla., Center for Natural Resources, IFAS, Gainesville, FL.

Izuno, F.T; Capone, L.T.1995. Strategies for protecting Florida's everglades: the best management practice approach. *Water Sci.Technol.* 31:123–131

Kennelley, E.D.; Mylavarapu, R.S. 2002. Low-level phosphorus analysis in the presence of silicate. *Comm. Soil Sci. Plant Anal*. (special Issue), 33: 3189-3201.

Li, Y.C.; Bryan, H.H.; Klassen, W.; Lamberts, M.; Olczyk, T. 1997. Sweet Corn Production in Miami-Dade County, Florida EDIS document HS862, Department of Soil and Water Science Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, September 2001. available on-line at http://edis.ifas.ufl.edu/TR013. (verified March 14, 2004).

Lerch, R.N.; Blanchard, P.E.; Thurman, E.M. 1998. Contribution of hydroxylated atrazine degradation products to total atrazine load in Midwestern streams. *Environ. Sci. Tech*. 32:40-48.

Li, Y.C. 1999. Sun Hemp – a new cover crop for South Florida. *Vegetarian* 99, 1-2.

McPherson, B.F.; Miller, R.L.; Haag, K.H.; Bradner, A. 2000. *Water Quality in Southern Florida, 1996–98: U.S. Geological Survey Circular 1207*, 32 p., available on-line at http://pubs.water.usgs.gov/circ1207/ (verified March 14, 2004).

Pfeuffer, R.J.; Matson, F. 2003. Pesticide Monitoring in South Florida: December 1998 to March 2003. South Florida Water Management District, West Palm Beach, FL. available on –line at http://www.sfwmd.gov/curre/pest/pestindex.htm (verified March 14, 2004)

Potter, T.L.; Marti, L.; Belflower, S.; Truman, C. 2000. Multiresidue analysis of cotton defoliant, herbicide, and insecticide residues in water by solid-phase extraction and GC-NPD, GC-MS, and HPLC-diode array detection. *J. Agric. Food Chem*. 48, 4103-4108.

Simonne, E.; Hochmuth, G., 2003. Cover *Crops in the BMP Era for Vegetable Crops Grown in Florida.* University of Florida Cooperative Extension Service, Gainesville, FL.

USDA-NRCS, 2004. *Classification of the Soils (SS of Dade, Florida).* USDA-Natural Resources Conservation Service, Washington, D.C. available on-line at http://soils.usda.gov/survey/online_surveys/florida/dade/classify.html#krome (verified on March 14, 2004).

USDA-OPMP, 1999. *Crop Profile for Corn (Sweet) in Florida*. Office of Pest Management Policy and Pesticide Impact Assessment, North Carolina State University, Raleigh, NC. Available on-line at http://pestdata.ncsu.edu/cropprofiles/docs/FLSweetcorn.html (Verified March 14, 2004).

USEPA. 2003. *Interim Re-registration eligibility decision for atrazine, case no. 0062*. http://www.epa.gov/oppsrrd1/REDs/atrazine_ired.pdf (verified March 12, 2004).

USGS, 2004. *Water-Quality Data from the Ground-water Program of the Southern Florida Study Unit of the U. S. Geological Survey National Water-Quality Assessment (NAWQA) Program.* Available on-line at http://fl.water.usgs.gov/Sofl/gw/gwintro.html (verified March 14, 2004)

Vanderheyden, V.; Debongnie, P.; Pussemier, L. 1997. Accelerated degradation and mineralization of atrazine in surface and subsurface soil materials. *Pest. Sci*. 49:237-242.

Wang, Q.; Bryan, H.; Klassen, W.; Li, Y.C.; Codallo, M.; Abdul-Baki, A. 2002. Improved tomato production with summer cover crops and reduced irrigation rates. *Proc. Fla. State Hort. Soc*. 115:202-207.

Zhang, J-Z.; Fisher, C.J.; Orter, P.B. 1999. Optimization of performance and minimization of silicate interference in continuous flow phosphate analysis. *Talanta* 49:293-304.