Evaluation of Soil Phosphorus and Phosphorus in Water Discharged from Three Everglades Agricultural Area Farms

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Table of Contents

List of Figures

List of Tables

Introduction/Literature Review

The Everglades Ecosystem

The Everglades ecosystem, situated in south Florida, was historically a hydrologically connected wetland system that began north of Lake Okeechobee in the Kissimmee River "valley" and extended to its outflows at the southernmost part of the Florida peninsula in Florida Bay. The Everglades system originally covered 1.17 million ha prior to drainage projects that began in the late 1800's (Figure 1).

The historic Everglades is an ecosystem comprised primarily of sawgrass plains, wet prairies, sloughs, and tree islands. The drainage projects begun in the late 1880's ultimately resulted in a system containing 2400 km of canals and dikes which created a compartmentalized landscape containing, from the north, the Everglades Agricultural Area (EAA), Water Conservation Areas (WCA) 1, 2, and 3, and Everglades National Park (ENP) (Davis et al., 1994) (Figure 2).

Phosphorus in the Everglades

Historically, the primary source of phosphorus to the Everglades system was rainfall. With the physical changes to the system, other sources of phosphorus, such as urban and agricultural runoff began to play a large role in the evolution of the landscape from a phosphorus-limited oligotrophic system to a phosphorus enriched system (Davis et al., 1994). Phosphorus enrichment has resulted in changes to the structure and function of the ecosystem (Noe, 2001). Phosphorus loading from the Everglades Agricultural Area is believed to be the primary cause of eutrophication in the Everglades. Gaiser et al. (2005) found that the Everglades marshes have a near-zero assimilative capacity for phosphorus without a change to the ecosystem.

The Everglades Agricultural Area

The Everglades Agricultural Area (EAA) is a 283,300 ha tract of land located between Lake Okeechobee on the north side, sand lands on the northeast and west sides and the natural remnants of the Everglades to the south and southeast (Figure 2) (Izuno, 1994).

The EAA was created from land that was part of the historic Everglades system and provides an important hydrologic link from Lake Okeechobee to the Everglades. Water from Lake Okeechobee flows generally south down four major canals toward the water conservation areas at the north end of the remaining Everglades. Along the way, water from the canals is used for irrigation and is mixed with runoff water from the farms. Prior to entering the water conservation areas, the water is treated to remove phosphorus in stormwater treatment areas.

Everglades Agricultural Area Soils

Histosols are the dominant soils in the EAA. The soils formed over an impermeable limestone formation when organic matter began to accumulate in this area about 4,400 years ago. Snyder (1994) estimated that the accumulation of peat was at a rate of 8.38 cm/100 yrs beginning about 4,000 years ago until the drainage of the region began in the early 1900’s. Peat accretion studies in the water conservation areas have resulted in estimated rates of peat accretion of 1.1 cm/yr (Reddy et al., 1993; Craft and Richardson, 1993).

The seven Histosols that are now recognized in the EAA are Torry muck, Terra Ceia muck, Pahokee muck, Lauderhill muck, Dania muck, Okeechobee muck, and Okeelanta muck. All but the Okeelanta muck are underlain by limestone (Snyder, 1994). The profile characteristics of these soils as mapped in 1974 are summarized in Table 1 (Snyder, 1994). The reported thickness of the organic layer in these muck soils in 1974 may be significantly less now due to the effects of mineralization.

The EAA Histosols are highly decomposed with an organic matter content >80% (Snyder and Davidson, 1994). The depth of the O horizon to the limestone bedrock in the Histosols located close to the east and south shores of Lake Okeechobee are generally greater than 1m, while soils further south and east of the lake have depths less than 1m (McCollum et al., 1978, Cox et al., 1988).

In the late 1800's, drainage of the EAA soils was begun to allow for human habitation. The aerobic soil environment has allowed for mineralization of the Histosols and subsidence at a rate that has averaged approximately 2.5 to 3 cm per year (Rice et al., 2002; Snyder, 1994). Shih et al. (1997) surveyed subsidence rates along the established survey line and found that in the 19 years after 1978, subsidence had been reduced to 1.4 cm per year.

Cultural Practices

Crops grown in the EAA include sugarcane, green beans, sweet corn, leafy greens, rice and sod. Sugarcane is the dominant crop; vegetable and rice crops are rotational crops. Sugarcane is planted generally September through January and is grown as a perennial crop with the harvest taking place between October and April. Sugarcane grown on the Histosols of the EAA requires relatively low phosphorus fertilizer input (Coale, 1994).

Depending on whether the sugarcane is plant cane or a ratoon crop, the desired level of water extractable soil phosphorus is in the range of 7 to 11 mg/kg (Sanchez, 1990).

Vegetable production in the EAA has maintained high economic importance since the mid-1900’s. Two to seven vegetable crops can be grown on a single piece of land every crop season. Planting of vegetable crops occurs from August to May with fertilizer application at every planting based upon soil test results (Schueneman and Sanchez, 1994). Depending on the vegetable crop, the desired level of water extractable soil phosphorus is in the range of 9 to 27 mg/kg, For radishes, the recommendation is 9 mg/kg. For sweet corn, the recommendation is 15 mg/kg. For celery, it is 18 mg/kg and for escarole, endive and romaine lettuce, it is 27 mg/kg (Hochmuth et al, 1996).

The EAA provides excellent growing conditions for sod production. The organic soils have high water retention capacity and substantial nitrogen availability. Prior to planting, sod fields may be leveled, flooded, and treated for pesticides. Application of phosphorus fertilizers prior to establishment of sod cover is relatively intense with monthly applications. After establishment of cover, fertilization is reduced to bimonthly applications based upon soil test results (Cisar et al, 1994). Rice production is a relatively small industry in the EAA. The crop is planted in the EAA from February through May with harvest occurring 115 to135 days thereafter. Rice fields are flooded three to five weeks after planting and remain flooded until ten to fourteen days before harvest. Since the rice crop is capable of utilizing native fertility, application of phosphorus fertilizer is not required (Jones et al., 1994).

Each EAA crop has its own water management strategy (Rice et al., 2002). The flat topography and impermeable limestone bedrock make the area well-suited to flood/seepage irrigation. In the EAA the water table is elevated or lowered by controlling water elevation in adjacent ditches and canals(Rice et al., 2002). The system for managing water on a farm consists of farm canals, lateral ditches and field ditches. Water can be moved onto or off a farm by gravity flow or pumping. Generally, water moves laterally through the soil into the fields for irrigation or laterally in the opposite direction during drainage. Some surface runoff may occur during heavy rainfall (Snyder et al, 1978).

The water table is managed at different depths depending upon a number of factors, including crop type. The data indicates that most vegetable crops had the highest yield and quality with the water table at 61 cm. Sugarcane was found to have its best growth with the water table at 76.2 to 91.4 cm. Maintaining the water table at 30.5 cm during establishment and up to 61 cm afterward was found most favorable for sod crops (Snyder et al., 1978).

Soil Phosphorus Cycling

Organic phosphorus is found in plants, detritus, microorganisms and decomposition byproducts in the soil. Organic phosphorus is cycled in soil by microbial activity. The cycle includes uptake of phosphorus by soil microorganisms, turnover of microbial phosphorus and mineralization of microbial byproducts. As organic compounds in soil are broken down or mineralized, inorganic phosphorus is released. As inorganic phosphorus is taken up or immobilized, organic matter is built up (Reddy and DeLaune, 2008).

Inorganic phosphorus can be found in the nonlabile, labile and soluble phosphorus pools. In the nonlabile pool, it can be found tightly bound in primary phosphorus-bearing minerals. In the labile pool, it can be found bound to calcium, iron or aluminum minerals where it can be loosely bound or precipitated. In the soluble pool, phosphorus is present as orthophosphates which are readily available to plants for uptake. The solubility of phosphorus in the soil solution is determined by pH. In high pH soils, the solubility is determined by calcium compounds. In acid soils, the solubility is determined by iron and aluminum compounds. In the EAA, the depth of the tilled zone to the underlying limestone is decreasing as the organic soils mineralize. The pH of the soils would also be expected to increase, reducing the availability of phosphorus for crop uptake (Hochmuth et al, 1996).

There are a number of methods for testing phosphorus in soil which discern the soluble, labile, and nonlabile phosphorus fractions (McGechan, 2002). Ivanoff (1998) developed and applied a phosphorus fractionation method that was well-suited to organic soils. Castillo and Wright (2008) modified the Ivanoff method in which a water extract was used for determination of soluble phosphorus followed by a NaOH extraction to determine iron and aluminum bound phosphorus then a final extraction by a weak HCl solution to determine calcium bound phosphorus. The remaining sample was then digested with HCl and analyzed for residual P. The humic–fulvic acid fraction was determined by further digesting the soluble extract with H_2SO_4 and subtracting it from the NaOH total phosphorus. Measurement of the phosphorus fractions was by the ascorbic acid-molybdenum blue method using a discrete analyzer.

Soil Phosphorus in the EAA

In 1983, Nicholson reported that inorganic phosphorus in Everglades Histosols represented 24% of the total phosphorus content, while in cultivated Everglades soils the inorganic phosphorus content was usually around 50% and sometimes as high as 72%. This was attributed to phosphorus fertilization (Sanchez and Porter, 1994).

Soil microorganisms immobilize phosphorus by transforming inorganic phosphorus to organic forms and mineralize phosphorus by breaking down organic constituents and releasing inorganic phosphorus. Mineralized phosphorus can be utilized by soil microorganisms or plants, immobilized as inorganic phosphorus or lost from the soil altogether through stormwater runoff (Sanchez and Porter, 1994). Castillo and Wright (2008) studied soil phosphorus as associated with different land uses in the EAA. They found that the soil phosphorus in the cultivated soils was about 50% organic.

Wright (2009) studied the phosphorus fraction bound to Fe and Al oxides in Histosols. Soil phosphorus may move in and out of this fraction due to fluctuating redox conditions under different environmental conditions. In the sugarcane farm studied, the calcareous nature of the soil promoted the sequestration of phosphorus into the Ca-bound to a greater extent than the Fe-Al bound fraction. Even so the Fe-Al bound phosphorus was significantly higher for sugarcane than other land uses throughout the soil profile.

Transport of Soil Phosphorus

Domagalski et al. (2008) studied nutrient transport processes in five watersheds across the United States in different climate conditions. The studies of drainage pathways, which included tile drains, overland flow and groundwater discharge, found that overland flow contributed the greatest nutrient loads. Results of total phosphorus and orthophosphate analyses indicated that the dissolved phosphorus ranged between 2.9 % and 48.2% of the total for the streams studied.

Hortenstein and Forbes (1972) compared the phosphorus content of organic soils in central Florida. The soils were in the same vicinity but in different stages of being cleared. The soil under natural saturated conditions had relatively low orthophosphorus content. In the recently cleared area, phosphorus content increased 8 to 12 times higher than the natural area. The cultivated area had the highest phosphorus content which indicated that the peat soil contributed substantially to nutrients in the drainage water.

Drainage-water total phosphorus and dissolved phosphorus concentrations in the EAA were studied by Izuno et al. (1991). They found that dissolved phosphorus comprised between 50 and 80% of the total phosphorus concentrations and that cropping practices and field conditions in the EAA have significant influence. Recommendations from the study included improvements in phosphorus fertilization practices and management of farm drainage.

Diaz et al. (1993) conducted laboratory studies of soluble phosphorus release from EAA Histosols. In simulated long-term flooded and drainage conditions, dissolved phosphorus was leached from five different organic soils from the EAA. Phosphorus released from flooded soils was found to be higher than the drained counterparts indicating that higher phosphorus release occurs under periodic flooding and draining.

Particulate phosphorus discharged from EAA farms has been studied extensively. Farm ditches and canals have been found to support aquatic plant growth which is the primary source of particulate phosphorus is farm discharge water. The phosphorus fraction of the aquatic system is significantly greater than that of the organic soils and plant materials in the fields. Aquatic plant materials and related solids move through the drainage system suspended throughout the water column. Because biomass is heterogeneous, erosion rates and sedimentation velocities vary (Daroub et al, 2002a).

Daroub et al. (2002b) also found that high velocity is the factor that has the greatest influence on particulate phosphorus transport. As discharge water flows from a farm by gravity or pumping, mild to moderate turbulence conditions are induced. The first fraction of particulate phosphorus, which is light and mobile, can easily be re-suspended. The fraction that is more strongly associated with the sediments or aquatic vegetation requires higher velocity to induce shear stress to dislodge it. The higher velocity may mobilize large amounts of particulate phosphorus. The final fraction consists of randomly generated particulates generated during events that do not occur regularly.

Surface and Subsurface Discharge of Phosphorus

Fertilized soils are the most important source of phosphorus loading to surface waters (Gachter et al., 2004). McGechan and Lewis (2002a) found that phosphorus tends to move with soil water in colloidal or particulate form on surfaces to which the phosphorus is adsorbed.

Miller (1979) studied nutrients in drainage water from mineral and organic soils and found that phosphorus in the drainage water from the organic soils increased during the course of the study. Laboratory studies linked the field observation to the P-adsorption capacity of organic soils which varied with the total Fe and Al contents of the samples.

Moog (2002) found that most transported phosphorus was adsorbed to particulate matter and that phosphorus loads decreased as conservation methods were employed.

Patrick and Khalid (1974) concluded that the difference in sorption and release of phosphorus in soils can be attributed to the capacity of iron oxides to sorb and release orthophosphate. Phosphate can be more readily solubilized where solution phosphate is low and more solution phosphate can be sorbed where solution phosphate is high and high surface area iron compounds are present in the soil.

Owens and Shipitalo (2006) evaluated phosphorus losses from fertilized pastures via both surface and subsurface flow. In this study, the investigators found that phosphorus lost in subsurface flow was low.

Surface and Subsurface Discharge of Phosphorus in the EAA

The processes controlling phosphorus release into drainage water from soil include mineralization-immobilization, dissolution-precipitation and adsorption-desorption of phosphorus in the soil.

In the EAA, phosphorus is measured in drainage water as dissolved phosphorus and particulate phosphorus. Total phosphorus and total dissolved phosphorus from the agricultural fields is influenced by cultural practices and field conditions (Izuno et al., 1991).

Following extensive studies of soils, sediments, suspended solids and biotic growth in EAA farm canals, Stuck et al. (2001) concluded that particulate phosphorus in the farm discharges is derived primarily from biological material growing in the farm canals.

Izuno and Bottcher (1991) showed that a significant fraction of the total phosphorus loading in drainage waters leaving the EAA is in the particulate form. The particulate phosphorus fraction accounted for 20 to 70% of the total phosphorus exported from EAA farms (Izuno and Rice, 1999). Izuno et al. (1991) reported that dissolved phosphorus concentrations in farm drainage water were 48 to 80% of TP values. It was also found on the farms studied that dilution, assimilation, and adsorption may be occurring between the field ditches and the pump stations since phosphorus concentrations in the field ditches were higher than those measured at the main farm pump stations. Increased phosphorus in water from drained fallow fields indicate that soil mineralization provides a significant contribution of the phosphorus concentrations found in drainage water.

Snyder et al. (1978) found that on-farm water table manipulation and flooding to control soil subsidence can have a significant effect on phosphorus released into drainage water.

Reddy (1983) studied the role of soil organic matter decomposition on the release of soluble phosphorus into drainage water. The amounts of soluble phosphorus released in drainage water was 70-89% of the total phosphorus in drainage water for organic soils of central Florida and 54-57% of the total phosphorus in drainage water for south Florida organic soils (Table 2).

A monitoring program was initiated in the EAA in 1992 and served as the basis of research on the effectiveness of Best Management Practices on representative farms. The data collected for this research included total phosphorus (TP) concentration, discharge volume, and daily rainfall amount (Daroub et al., 2009).

Factors Influencing Phosphorus Discharge from Farms

The University of Florida's Institute of Food and Agricultural Sciences (UF/IFAS) has conducted research on ten farms in the EAA related to factors influencing the phosphorus in stormwater discharges from the farms. Six of the farms were planted primarily in sugarcane during the study period. The remaining four farms were planted in mixed cropping systems, i.e., crops during the study included sugarcane, vegetables, sod, rice, trees, and melons (Daroub et al., 2009).

Daroub et al. (2007) identified the following factors that may impact phosphorus discharges from farms in the EAA:

- Water level management (canal elevations and head differences inside and outside the farm, pump to rainfall ratio)
- Cropping practices (percent sugarcane, percent flood, percent fallow and flood)
- Rainfall and irrigation (rainfall, irrigation demand, irrigation phosphorus concentration, irrigation phosphorus load)
- Farm specific factors (farm size, soil series, soil depth, location)

Best Management Practices are on-farm practices intended to reduce the phosphorus content in drainage waters to an environmentally acceptable level without negatively impacting the economic viability of the farming operation. There are four main categories of BMPs from which the growers are required to select: 1) calibrated soil testing and application of fertilizer based on soil test; 2) control of fertilizer application methods; 3) water management practices; and 4) sediment source and transport controls (Daroub et al., 2009). Bottcher and Izuno (1992) suggested that the 25% phosphorus reduction from BMPs was a reasonable and obtainable goal and that even higher reductions were potentially obtainable due to reduced drainage volumes as a result of BMP implementation.

Seven to ten years after implementing mandatory BMPs, a decreasing trend in phosphorus loads on sugarcane was observed in the EAA. Phosphorus loads on mixed crop farms showed either decreasing or insignificant trends, probably due higher phosphorus fertilizer rates compared to sugarcane, and the need to maintain low water tables. Other factors that may impact the success of BMPs in individual farms include cropping rotations, flooding of organic soils, and irrigation water quality (Daroub et al., 2009).

Daroub et al. (2009) recommended that the data be analyzed further using advanced statistical techniques including multivariate regression and classification and regression tree analysis to quantify the management and environmental factors that are affecting phosphorus loads in the EAA including the potential impact of irrigation water.

Grunwald et al. (2009) used tree-based modeling to investigate relationships among a variety of environmental factors, including water level management, cropping practices, soils, hydrology and farm specific properties, and phosphorus loads on the ten EAA farms.

Cropping history has been found to be a factor influencing soil phosphorus levels and is also a factor influencing phosphorus in water discharges from farms (Daroub et al., 2007).

Objectives of Study

The objective of this study was to investigate a possible relationship between phosphorus concentration in the soils of different EAA farms and the phosphorus concentration in water discharged from the farms in the EAA by conducting statistical analyses on soils data, water extractable soil phosphorus (Pw) and water discharge data, flow –weighted total phosphorus (FWTP) for the selected farm basins. FWTP concentration was used in this study rather than total phosphorus (TP) concentration in order to give each sample equal weight based upon discharge flow.

Daroub et al. (2007) assessed factors that impact phosphorus loading from farm runoff in the EAA. The parameters studied included four categories 1) water level management (drainage volume, inside and outside farm canal levels, drainage volume to rainfall ratio), 2) cropping practices (percent cane, percent flood, percent fallow plus flood), 3) irrigation and rainfall (irrigation demand pan and irrigation phosphorus load), and 4) farm-specific constants (farm size and soil depth).

Owens and Shipitalo (2006) evaluated phosphorus losses from fertilized pastures via both surface and subsurface flow. In this study, the investigators found that phosphorus lost in subsurface flow was low. Daroub et al. (2007) briefly addressed the interaction of soil water with the limestone bedrock and the removal of soluble phosphorus from drainage water via sorption and/or precipitation. However, there have been no published studies of subsurface loss of phosphorus in the EAA. Evaluation of Pw will address an additional factor that may be considered to characterize phosphorus transport mechanisms on farms in the EAA.

Approach/Methods

Farm Locations

The EAA is an area of 280,000 ha that was designated for agricultural production by Congress in 1945. Currently, the majority of the land is in sugarcane production. However, significant acreage has historically been in rotational crops. Three farm sites were selected for evaluation in this research project, one sugarcane farm and two mixed crop farms. The criteria for selection of the farms are as follows:

- Availability of phosphorus discharge data from UF/IFAS
- Availability of soil phosphorus data from UF/IFAS
- Diversity of cropping systems

All three farms have been studied extensively as part of the UF/IFAS best management practices research begun in 1992. Further, soil analysis for all three farms has been performed at the UF/IFAS lab in Belle Glade, Florida and has been made available for this study.

The farms are identified by a numbering system that protects the identity of the growers. Figure 4 shows all ten farms included in the Daroub study (Daroub et al., 2007). The three farms selected for this research project are UF9200A, UF9201A and UF9206A/B. A summary of the characteristics of each farm are shown in Table 3.

- UF9200A

Farm UF9200A is a 518 ha (1280 ac) farm located in the S-5A sub-basin of the EAA. A monoculture of sugarcane was grown on the farm during the period of study. The average soil depth on this farm was 1.16 m. The discharge monitoring on the farm was conducted from July 1992 to April 2002 (Daroub et al., 2009). Soil Pw data was available for at least one month per year for the years 1992 through 2002. Figure 4 shows the layout of the farm and its water management system.

- UF9201A

Farm UF 9201A is a 518 ha (1280 ac) mixed crop farm located in the S-6 sub-basin of the EAA. The crops grown on this farm included vegetables during the period of study. The average soil depth on the farm was 0.61 m. The discharge monitoring was conducted from July 1992 to December 1999 (Daroub et al., 2009). Soil Pw data was available for at least four months per year for the years 1992 through 2002. Figure 5 shows the layout of the farm and its water management system.

- UF9206A/B

Farm UF9206A/B is a 710 ha (1754 ac) mixed crop farm located in sub-basin S-5A of the EAA. The crops grown in rotation on this farm during the study period were sugarcane, vegetables, rice and sod. The average soil depth on the farm was 0.88 m. The discharge monitoring on the farm was conducted from July 1992 to April 2002 (Daroub et al., 2009). Soil Pw data was available for at least eight months per year for the years 1993 and 1995 through 2002. Figure 6 shows the layout of the farm and its water management system.

The soils on all three farms are Histosols of the Terra Ceia and Pahokee series with an organic horizon that is underlain by limestone (McCollum et al., 1978).

Farm Data

- Water Discharge Data Base

  The water discharge data base includes pump station ID, date, TP concentration (mg/L), discharge volume, FWTP concentration (mg/L), TP load (kg), daily rainfall amount, and sample type. Auto-samplers were generally used to collect time-composite discharge samples for a period of 14 to 21 days. In some cases, grab samples were collected which may lead to higher uncertainty and biased results derived from statistical analysis. In this database, spikes occur at high load discharge events and represent major contributions to the overall phosphorus loads discharged from a single location (Daroub et al., 2007).

  Even though possible limitations in the database related to sampling strategies have been identified, the discharge monitoring dataset provides a long-term series of phosphorus concentrations, drainage flows, and farm phosphorus loads that can be used for long-term trend analysis. For the three farms selected for this analysis, water discharge sampling was conducted for approximately seven years (1992 - 1999) for one farm, UF9202A, and for almost ten years (1992 – 2002) for the other two farms, UF9200A and UF9206A/B (Daroub et al., 2007). See Table 4 for a summary statistics of the FWTP concentration in discharges from the three farms.

- Water Extractable Soil Phosphorus (Pw) Data Base

Water extractable soil phosphorus (Pw) sampling results are available for each of the three farms for a period of time that overlaps with the water discharge sample collection effort described above. For farms UF9200A and UF9201A, soil data is available for almost ten years (1992 – 2002). For farm UF 9206A/B, soil data is available for almost eight years (1993, 1995 – 2002).

Generally, soils are sampled and tested to determine the proper amount of nutrients required for high yielding and efficient crop production prior to each planting. EAA farmers apply phosphorus fertilizers according to a calibrated soil test. The soil test data for all three farms includes pH results and a water extractable test for phosphorus (Pw). For UF9206A/B, an additional test for acetic acid-extractable phosphorus (Pa) was also performed. The Pa test measures labile and more tightly held “reserve” phosphorus (Glaz et al., 2000).

There is no documentation identifying the details of sampling events in the laboratory records so it is not possible to identify who collected the samples, how the samples were collected, or whether a representative sampling method was used. Even though the sampling strategy and the methods for soil sampling for the three farms in this study cannot be confirmed, it has been assumed that the generally applied field sampling method to obtain representative samples was followed. The accepted sampling methodology, as described by Sanchez (1990), is to take samples to a 15 cm depth and place in a container that will not contaminate the sample, such as a plastic bucket, for compositing. Starting about 30 meters from one end of the field, a minimum of 30 cores from a 16 hectare block is collected in a zigzag fashion across the field. Following the methodology, the composited cores are thoroughly mixed and a 1 liter subsample is then placed into a clean soil sample bag and delivered to the soil testing lab (Sanchez, 1990).

In the laboratory, a variety of analyses are routinely conducted, including Pw (mg/kg), potassium (mg/kg), pH and micronutrients. To begin the analyses, soil samples are prepared by air drying. Then to conduct the Pw analysis, water is used to extract phosphorus from the soil. The phosphorus content of the extract is then measured by the molybdenum blue method using a discrete analyzer (Sanchez, 1990).

Laboratory analysis report forms are generated once sample analysis is completed. The University of Florida Everglades Soil Testing Laboratory at the Everglades Research and Education Center in Belle Glade, Florida has archived hard copies of lab analysis reports dating back to at least 1992. The soil test data for all three farms were available at the Everglades Research and Education Center Belle Glade laboratory on the original report forms. Data for the three farms in this study was entered into MS Excel spreadsheets prior to regression analysis using SAS.

The soil tests results in this study represent conditions in the soil prior to crop fertilization. The soil test database consists of 517 individual soil sample results for farm UF9200A, 1,554 individual soil sampling results for farm UF9201A, and 916 individual soil sampling results for farm UF9206A/B. The only analytical parameter included in the database that was used in this study was Pw

The time periods represented by the soil sampling events for each farm differed based upon crop planting schedules and practices. Farm UF9200A, the sugarcane farm, had sampling events primarily during the winter months. Farm UF9201A, the vegetable farm, conducted sampling events throughout the year in almost every month. Farm UF9206A/B, the mixed sugarcane/vegetable farm, sampled more frequently than Farm UF9200A, but less frequently than Farm UF9206A/B.

Data Analysis

The soil Pw data for each farm was sorted by month. Every data point was included in the initial analysis of the data in which SAS was used to construct box plots. Then each month’s data was reduced to a monthly average for the SAS regression analysis. Linear regression was conducted using SAS to determine if Pw (mg/kg) can be used to predict FWTP concentration (mg/L).

Results and Discussion

Box plots of the Pw data were constructed using SAS to observe the data distributions for each farm on a monthly basis. The box plots, shown in Figures 7, 8 and, 9, graphically display the minimum and maximum range values, upper and lower quartiles, mean and median. These show that for the sugarcane farm, UF9200A, the Pw was generally lower than the other two farms which are mixed crop farms.

The Pw data were sorted and analyzed by month. There are a total of 27 monthly soil Pw averages and 118 monthly FWTP averages for farm UF9200A, 48 monthly soil Pw averages and 87 monthly FWTP averages for farm UF9201A and 78 monthly Pw averages and 118 monthly FWTP averages for farm 9206A/B. The monthly averages for all three farms, showing only data for months when both Pw and FWTP were available, are shown in Appendix A.

The monthly median soil Pw concentration was 14.1 mg/kg with a range of 2.0 mg/kg to 134.3 mg/kg for farm UF9200A. The monthly median soil Pw concentration was 22.3 mg/kg for farm UF9201A with a range of 2.6 mg/kg to 53.3 mg/kg. The monthly median soil Pw concentration was 13.6 mg/kg for farm UF 9206A/B with a range of 6.9 mg/kg to 73.0 mg/k. These data are summarized in Table 5. The soil tests represented conditions in the soil prior to crop fertilization.

Linear regression was conducted using SAS to determine if Pw can be used to predict FWTP. Scatter plots of monthly Pw (mg/kg) and FWTP (mg/L) are shown in Figures 10, 11, and 12. The nearly flat line indicates no linear relationship between Pw (mg/kg) and

FWTP (mg/L). As can be seen, the R^2 for UF 9200A is 0.0088, for UF9201A is 0.0124 and for UF9206A/B is 0.0308, confirming that there is no linear relationship between monthly flow weighted total phosphorus in the farm discharges and the water extractable phosphorus in the soil.

In previous research at the three farms, Daroub et al. (2007) found that there were differences in the flow weighted TP discharged from three farms that may be linked to factors including water management, land use/cropping and soil depth. During the period of the study, farm UF9200A was a monoculture of sugarcane grown on soil with an average depth of 1.16 m. Farm UF9201A was a mixed crop farm growing vegetables during the period of study with an average soil depth of 0.61 m. Farm UF9206A/B was a mixed crop farm growing sugarcane, vegetables, rice and sod in rotation during the study period. The average soil depth on the farm was 0.88 m.

As can be seen in Tables 5 and 6, the sugarcane farm (UF9200A) had the lowest median annual flow-weighted TP at 0.237 mg/l and the next lowest median water extractable soil phosphorus at 14.14 mg/kg. The mixed crop farm growing sugarcane (UF9206A/B) had the next lowest median annual flow-weighted TP at 0.281 mg/l and the lowest water extractable soil phosphorus at 13.58 mg/kg). The mixed crop farm growing only vegetables had the highest median annual flow-weighted TP at 0.237 mg/l and also the highest water extractable soil phosphorus at 22.32 mg/kg. While it appears that there could be a relationship between median annual flow-weighted TP and water extractable soil phosphorus, the paired monthly data do not show a relationship.

Discussion of Results

The lack of a relationship suggests that other mechanisms are acting in the subsurface to influence the movement of phosphorus from the soil. The processes controlling phosphorus release into drainage water from soil include mineralization-immobilization, dissolution-precipitation and adsorption-desorption of phosphorus in the soil. In evaluating soil depth as a factor that may affect farm drainage volume and drainage water phosphorus concentration, Daroub et al. (2007) addressed the interaction of soil water with the limestone bedrock and the removal of soluble phosphorus from drainage water via sorption and/or precipitation. Soil phosphorus may move in and out of the fraction to which phosphorus is bound due to fluctuating redox conditions under different moisture regimes. Further, Janardhanan and Daroub (2010) found that phosphorus sorption in organic soils of the Everglades Agricultural Area is affected by Fe and Al oxides.

Flood/seepage irrigation is used to manage the water table at different depths depending upon crop type and may be a factor creating conditions that would affect the retention of phosphorus in the subsoil. Actual concentrations of phosphorus species in the soil solution on the farms in this study has not been determined but may be useful to further address the fate of phosphorus in the soil that has not been taken up by the crop.

While no relationship was found between the two sets of data, there are components of the study design that may have impacted the statistical analysis, including uncertainty regarding the soil sampling design and methods and the lack of soil sampling events during all months of the year, especially months during which discharges from the farms occurred. The design of this study was to simply address the possibility of a relationship between soil phosphorus and phosphorus in the water discharged from the farms using existing data. The water discharge data had been collected according to a scientifically designed sampling strategy whereas the soil data was not collected for the purpose of scientific evaluation.

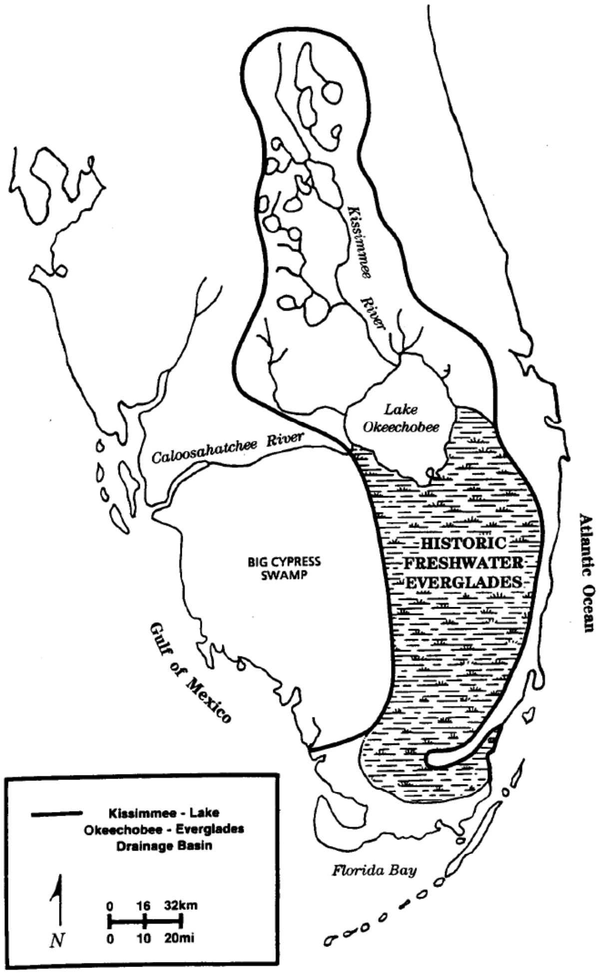


Figure 1. Location of Historic Everglades Watershed in South Florida (Davis et al., 1994)

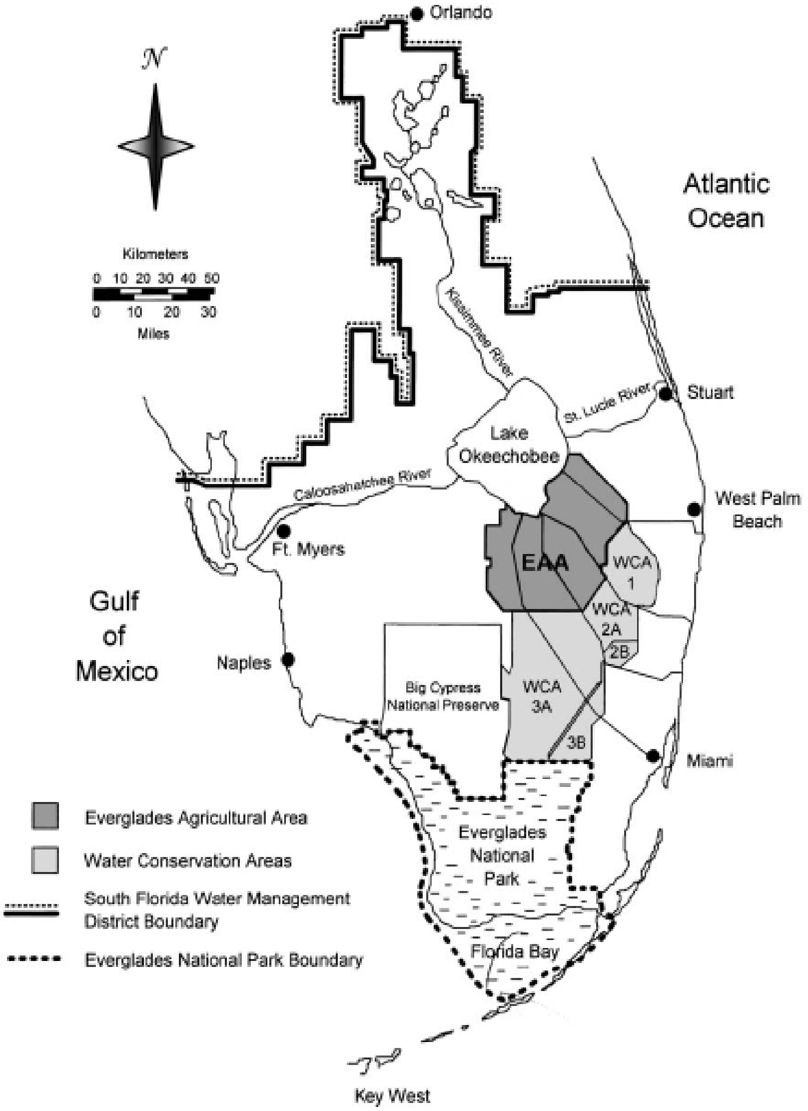


Figure 2. Location Map of the Everglades (Izuno, 1994)

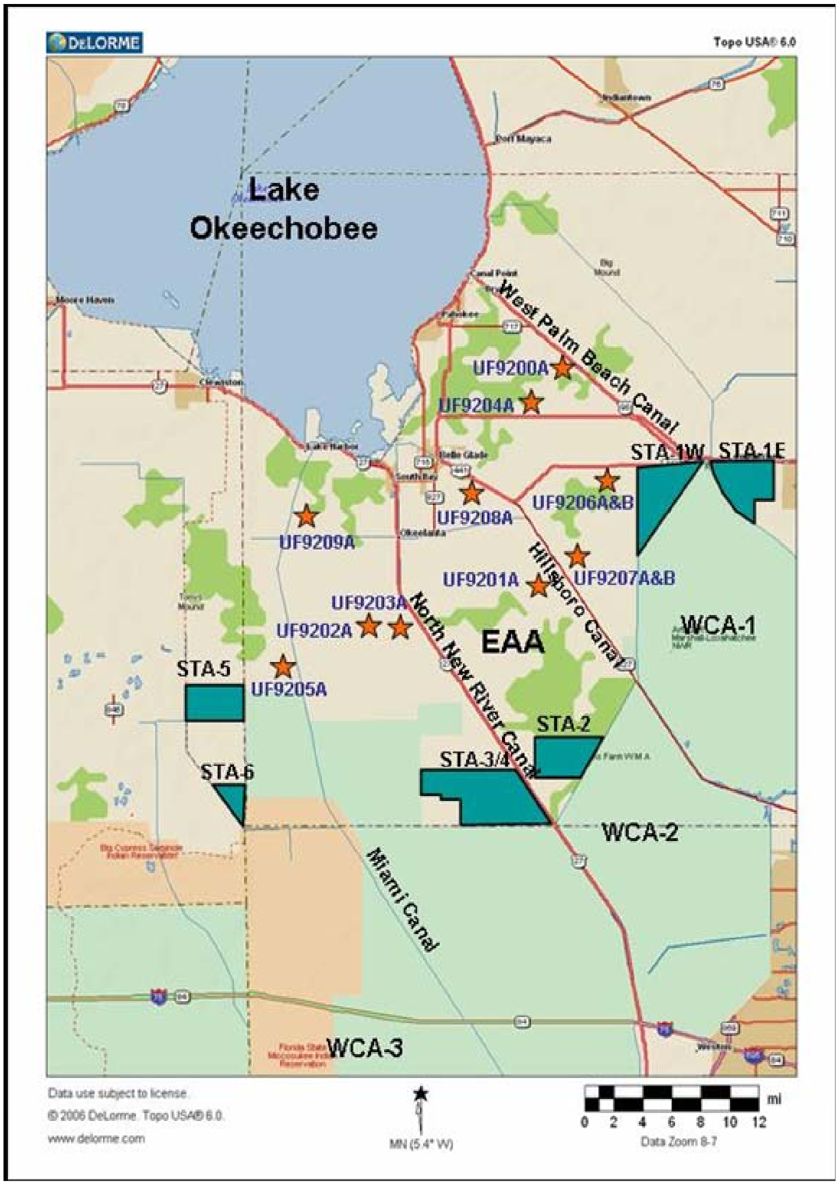
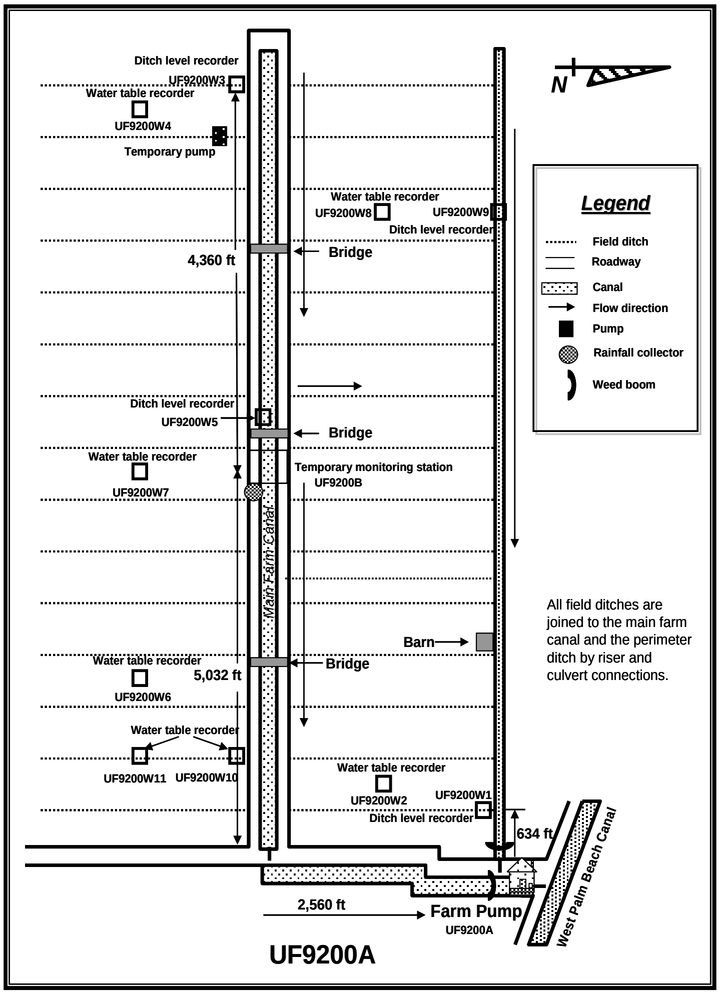


Figure 3. Location of Study Farms in the EAA (Daroub et al., 2007)



All field ditches are joined to the main farm canal and the perimeter ditch by riser and culvert connections.

Figure 4. UF9200A hydraulic system layout and general flow direction and monitoring system designations (Daroub et al., 2007)

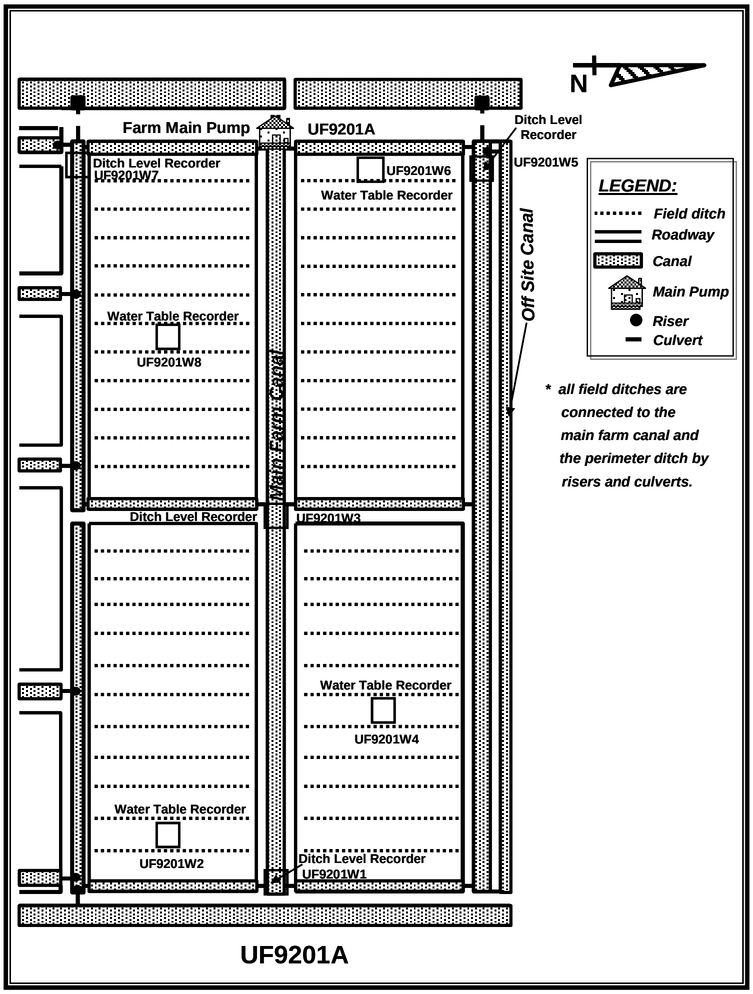


Figure 5. UF9201A hydraulic system layout and general flow direction and monitoring system designations (Daroub et al., 2007)

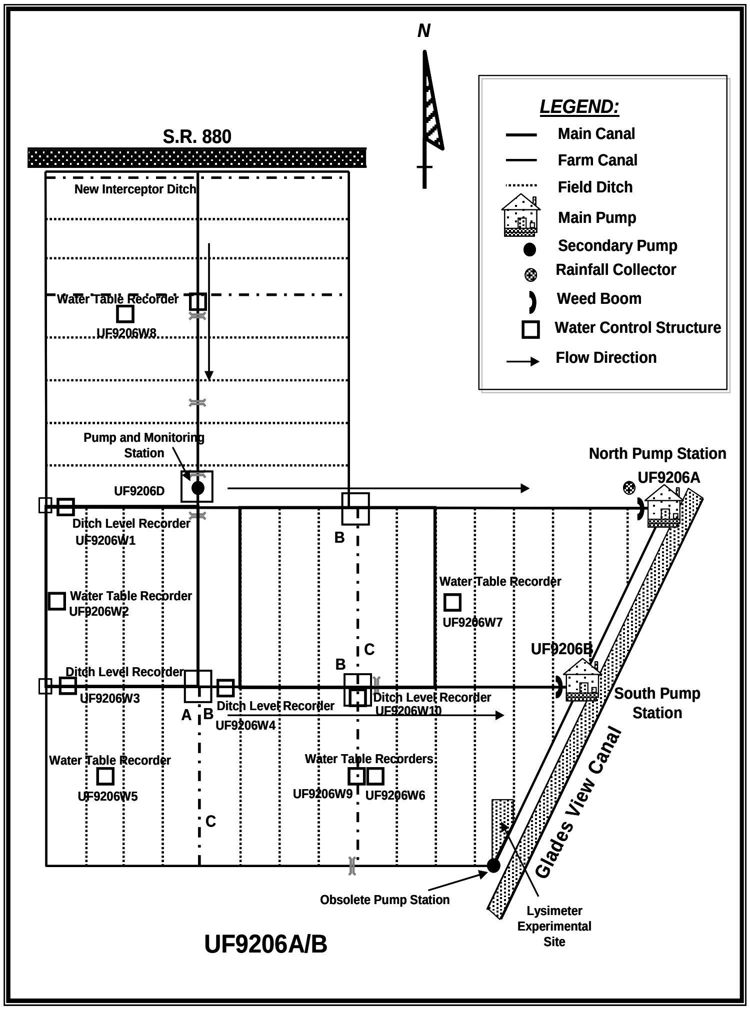


Figure 6. UF9206A/B hydraulic system layout and general flow direction and monitoring system designations (Daroub et al., 2007)

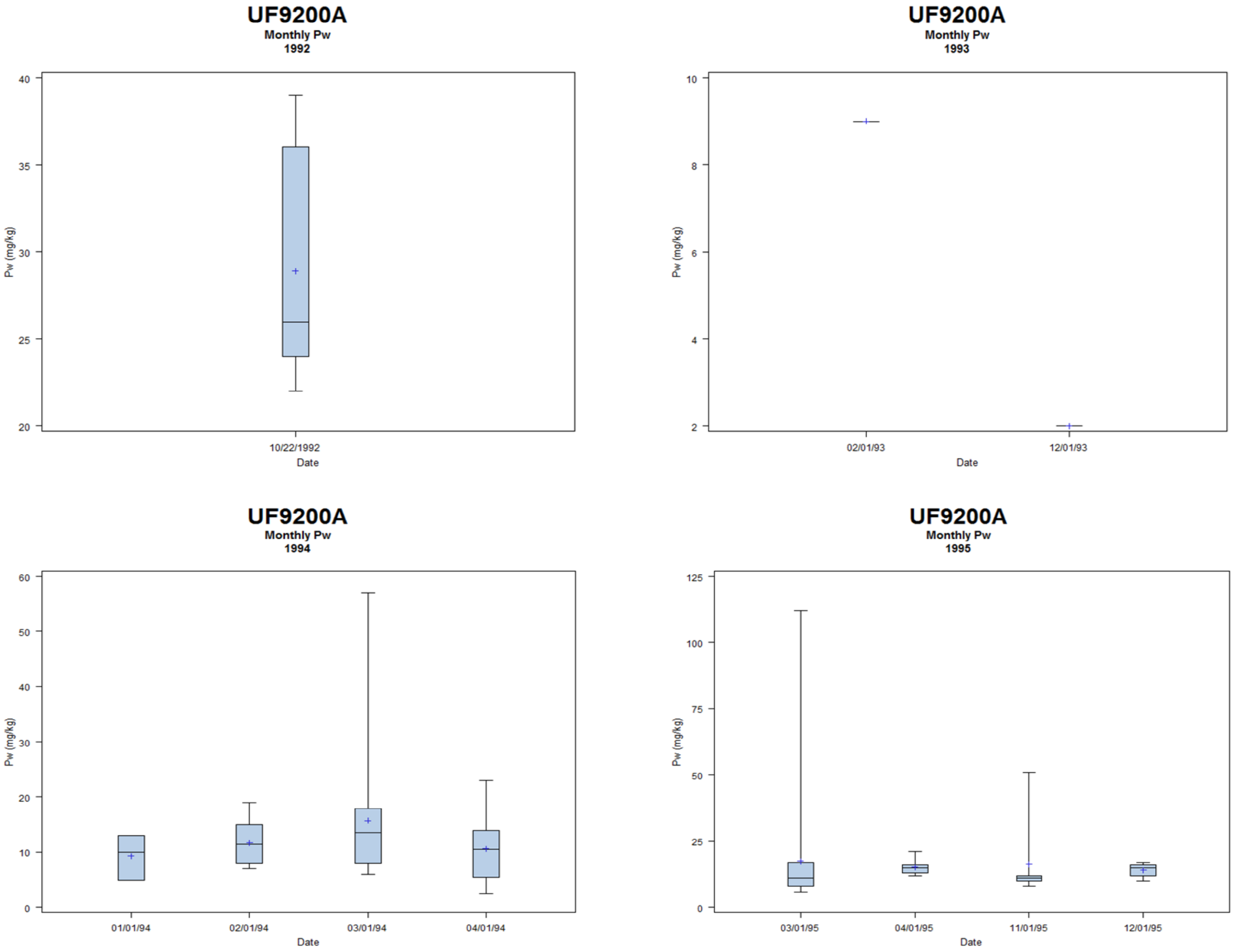


Figure 7. Box plots of PW by month for UF9200A (page 1 of 3)

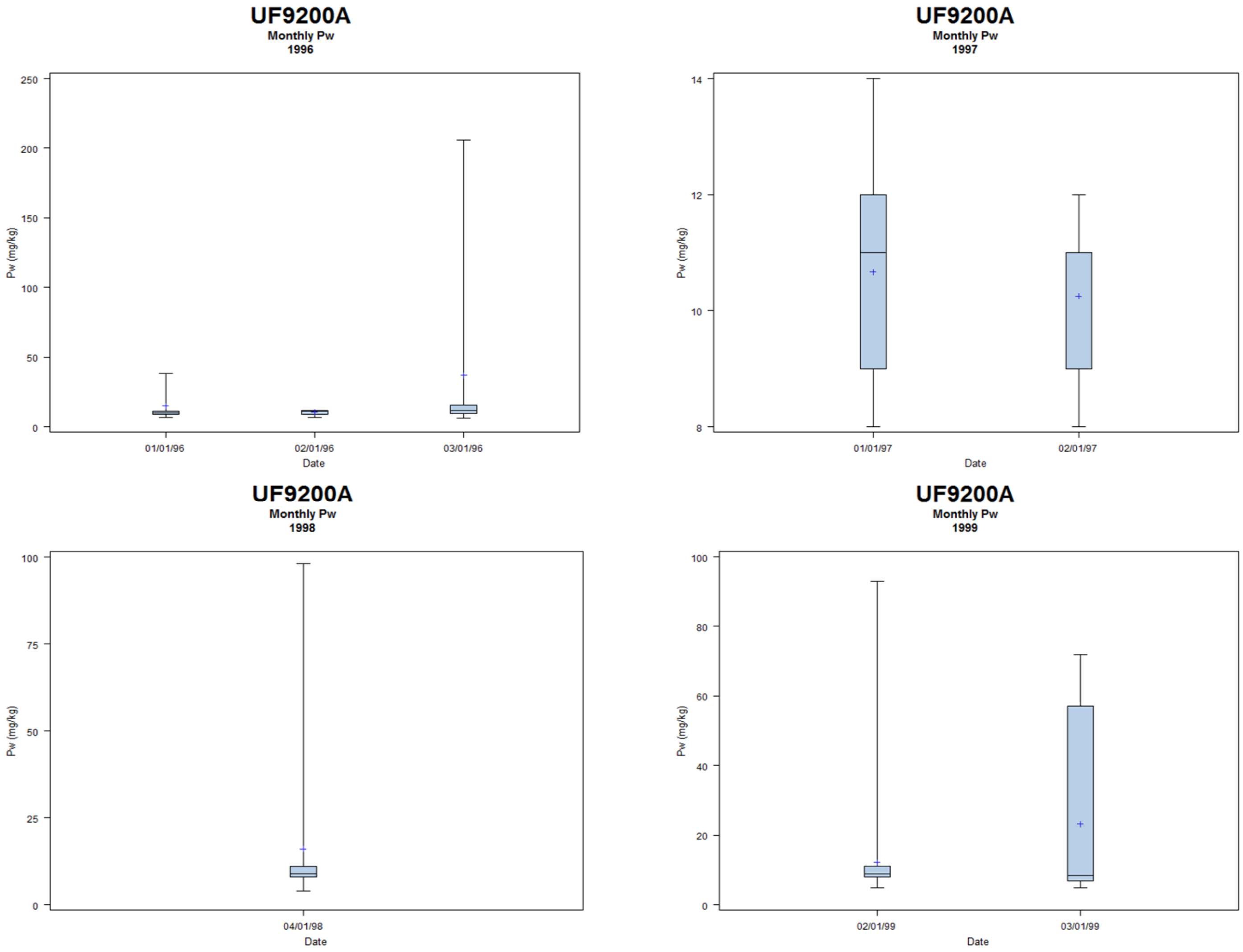


Figure 7. Box plots of PW by month for UF9200A (page 2 of 3)

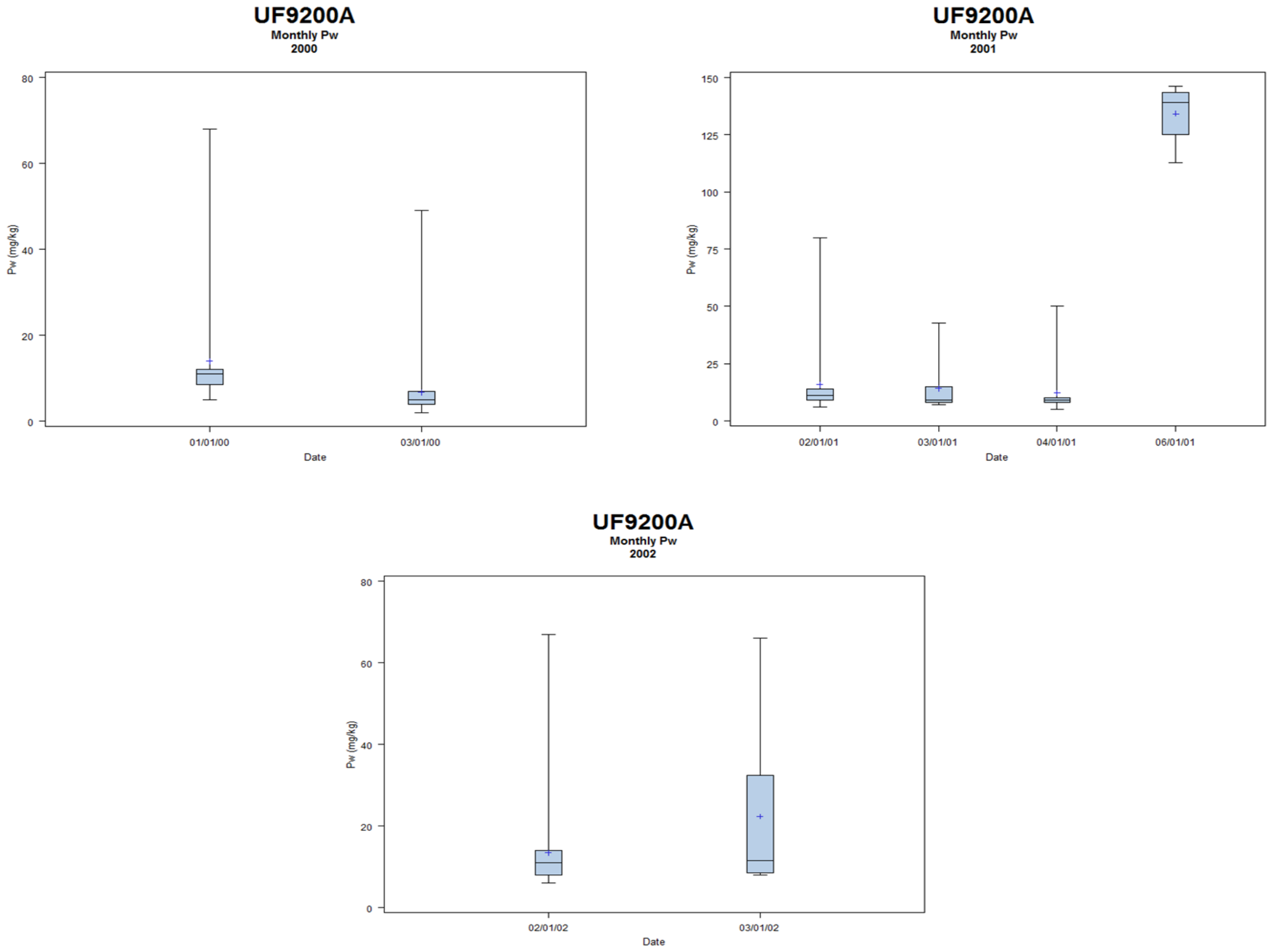


Figure 7. Box plots of PW by month for UF9200A (page 3 of 3)

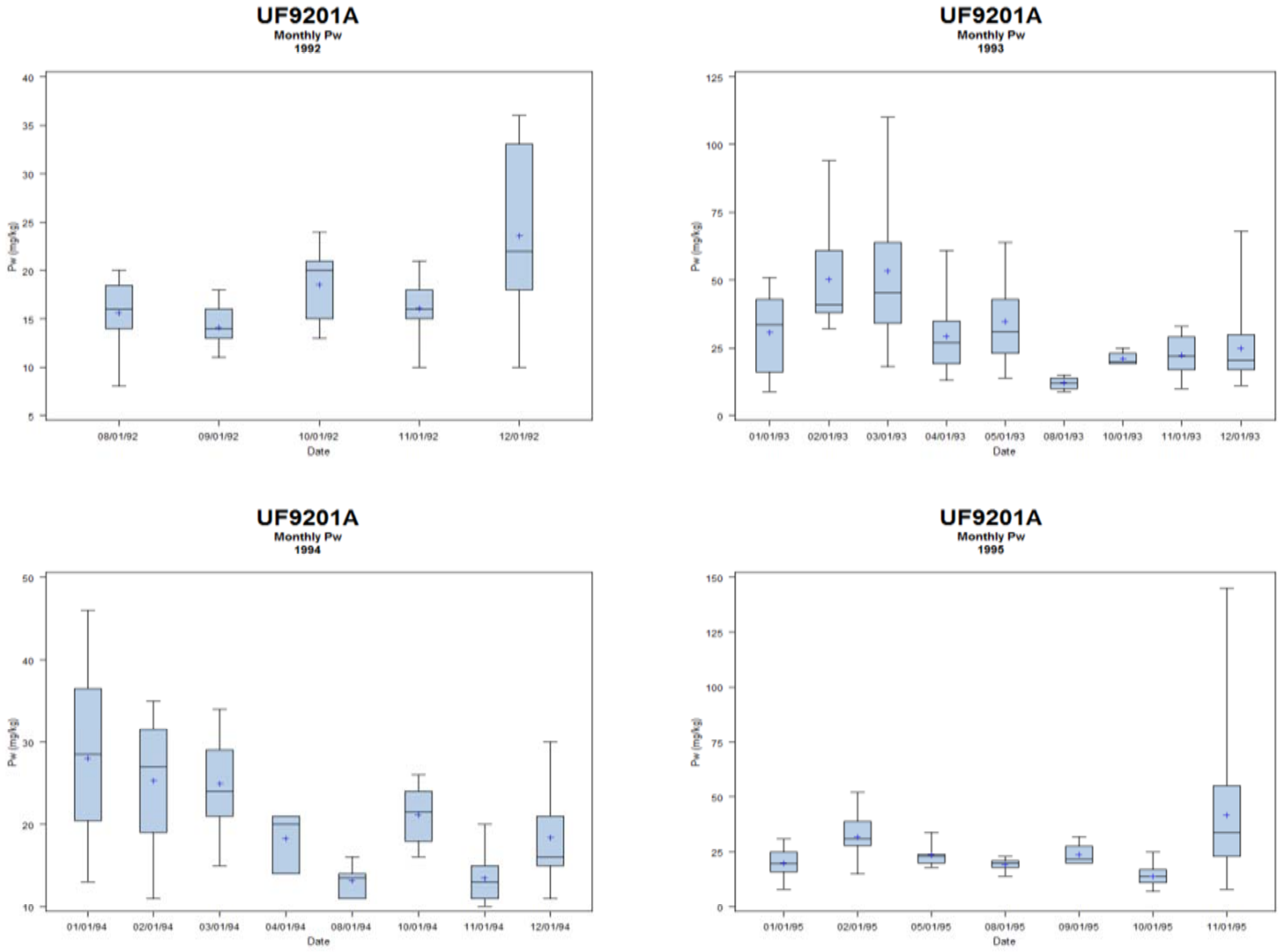


Figure 7. Box plots of PW by month for UF9201A (page 1 of 3)

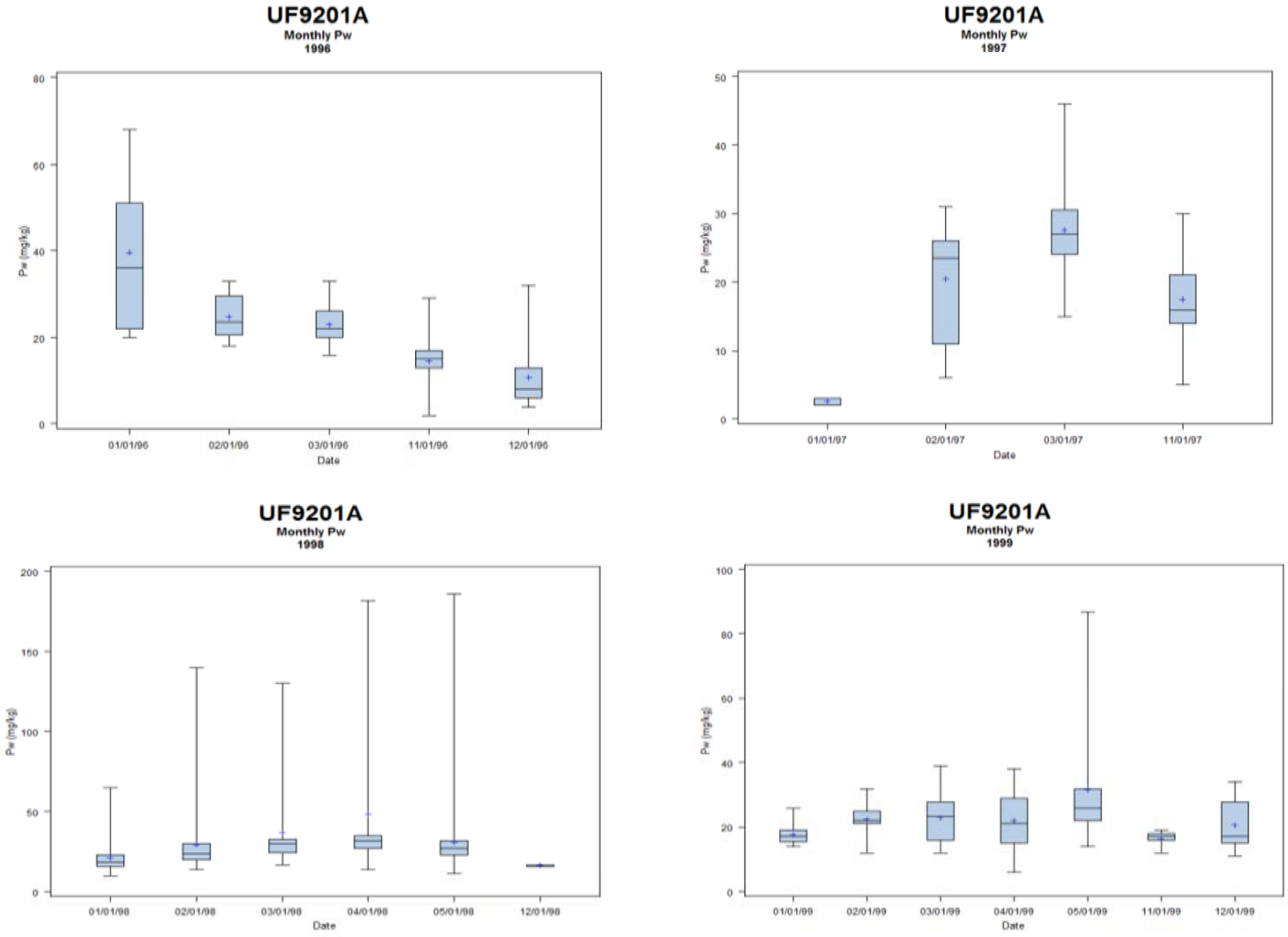


Figure 7. Box plots of PW by month for UF9201A (page 2 of 3)

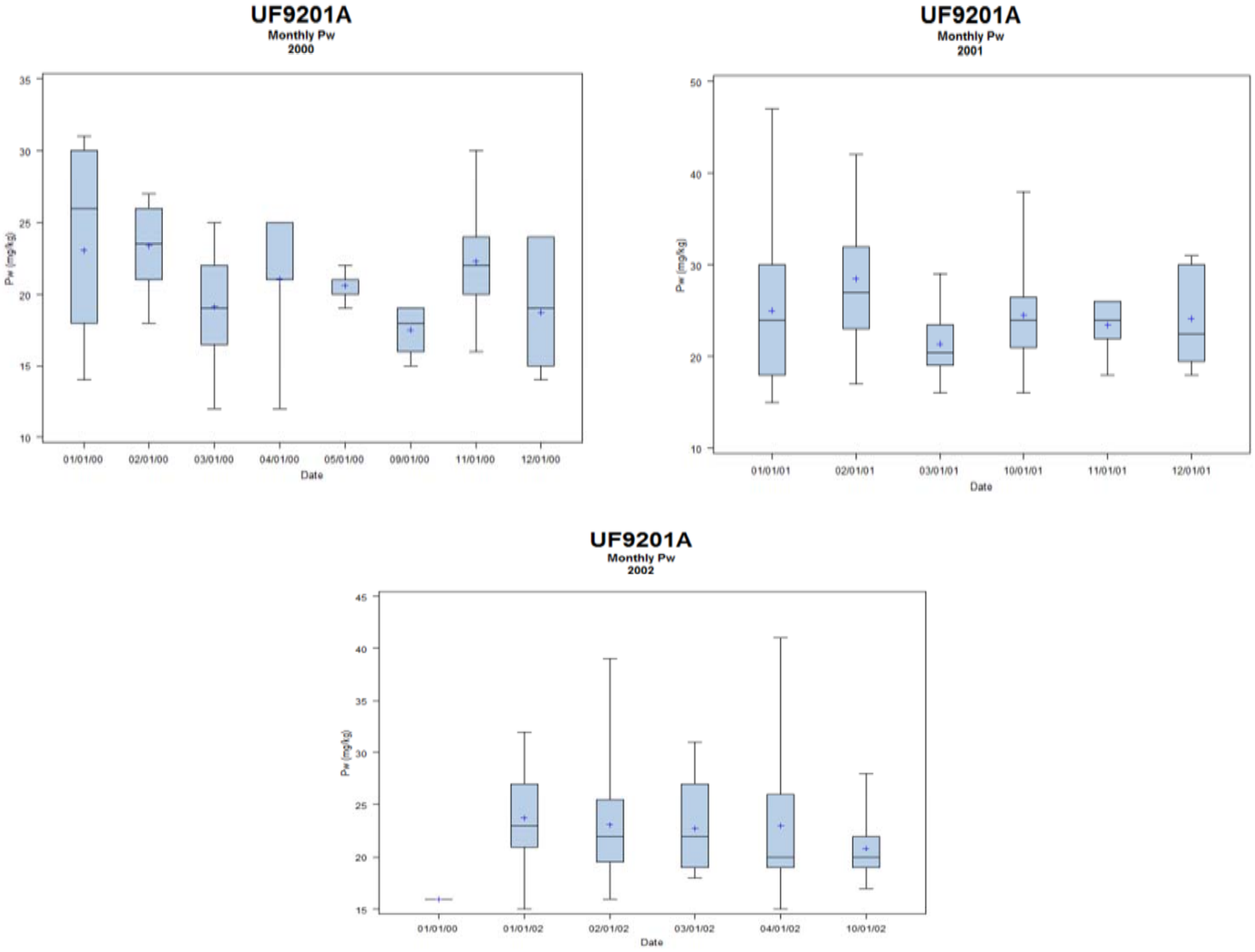


Figure 7. Box plots of PW by month for UF9201A (page 3 of 3)

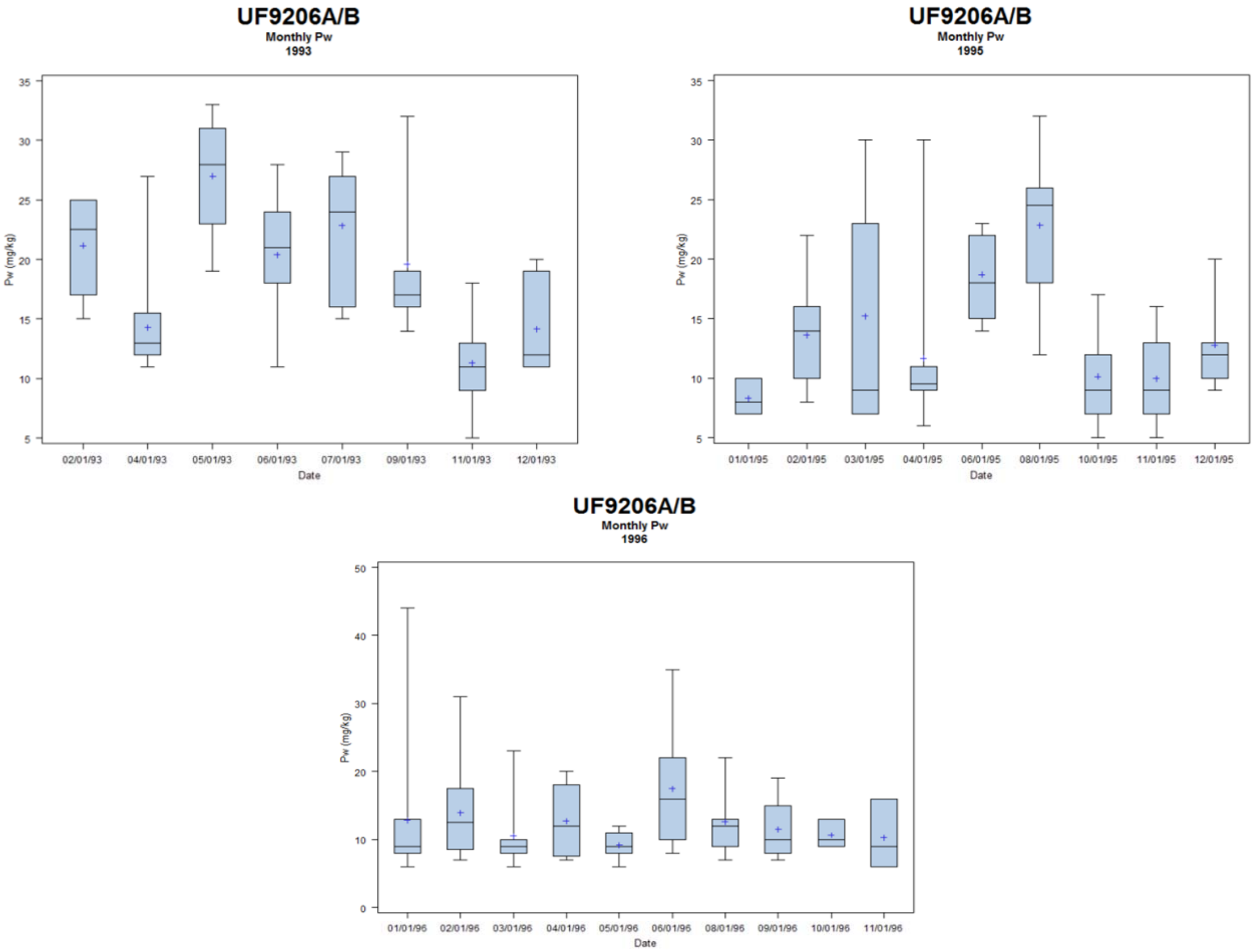


Figure 7. Box plots of PW by month for UF9206A/B (page 1 of 3)

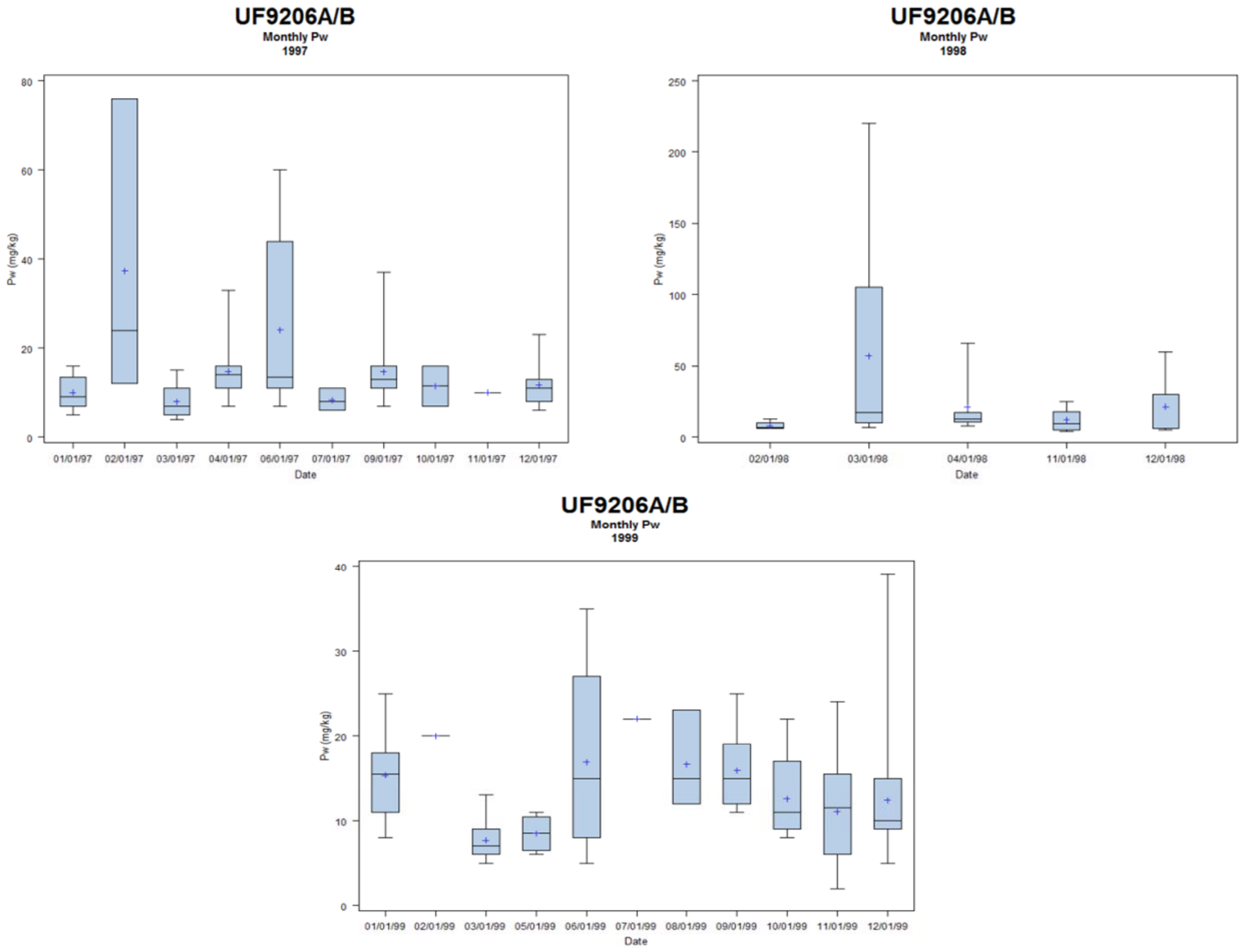
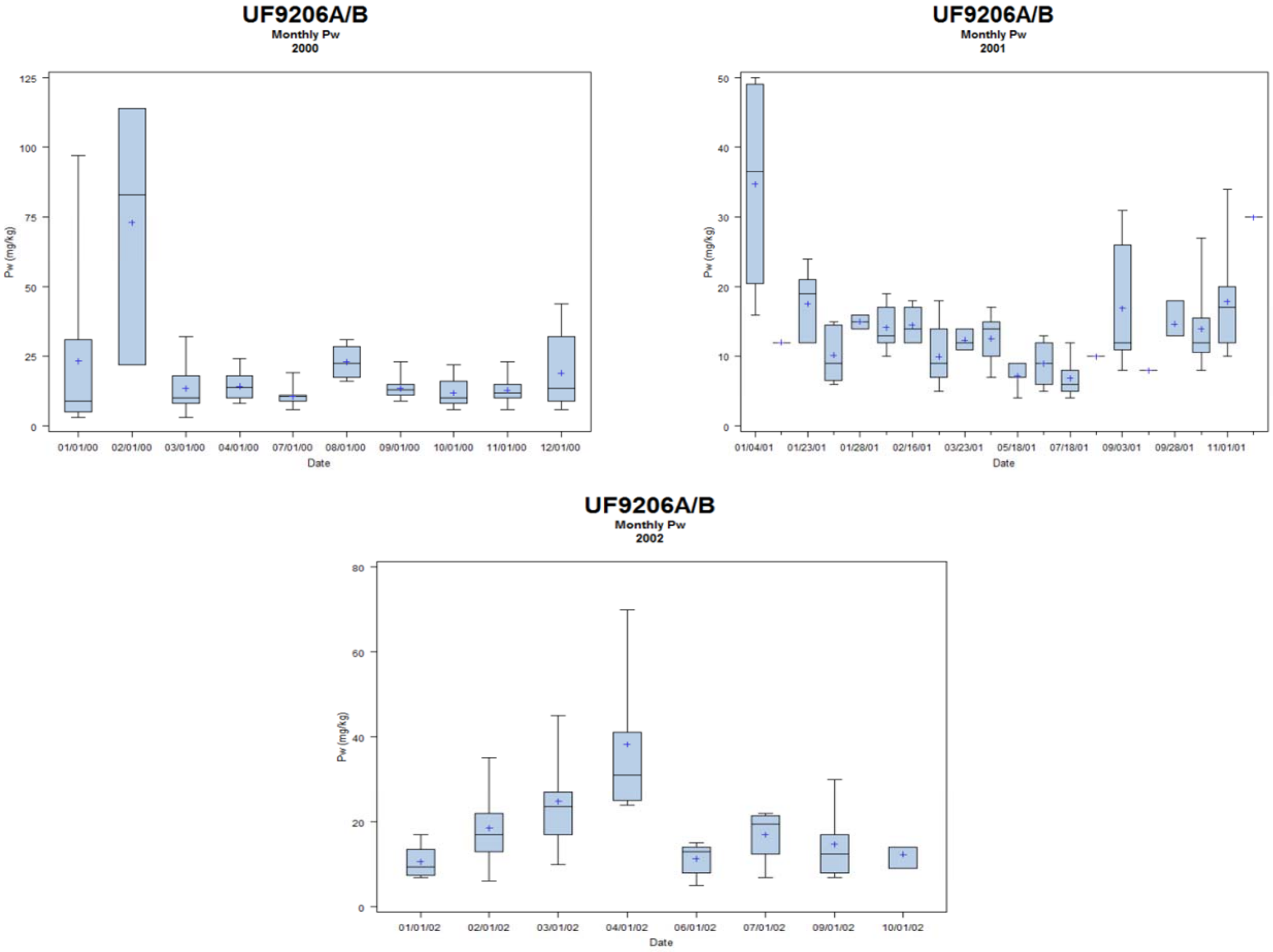


Figure 7. Box plots of PW by month for UF9206A/B (page 2 of 3)



UF9206A/B
Monthly Pw
2000

UF9206A/B
Monthly Pw
2001

UF9206A/B
Monthly Pw
2002

Figure 7. Box plots of PW by month for UF9206A/B (page 3 of 3)

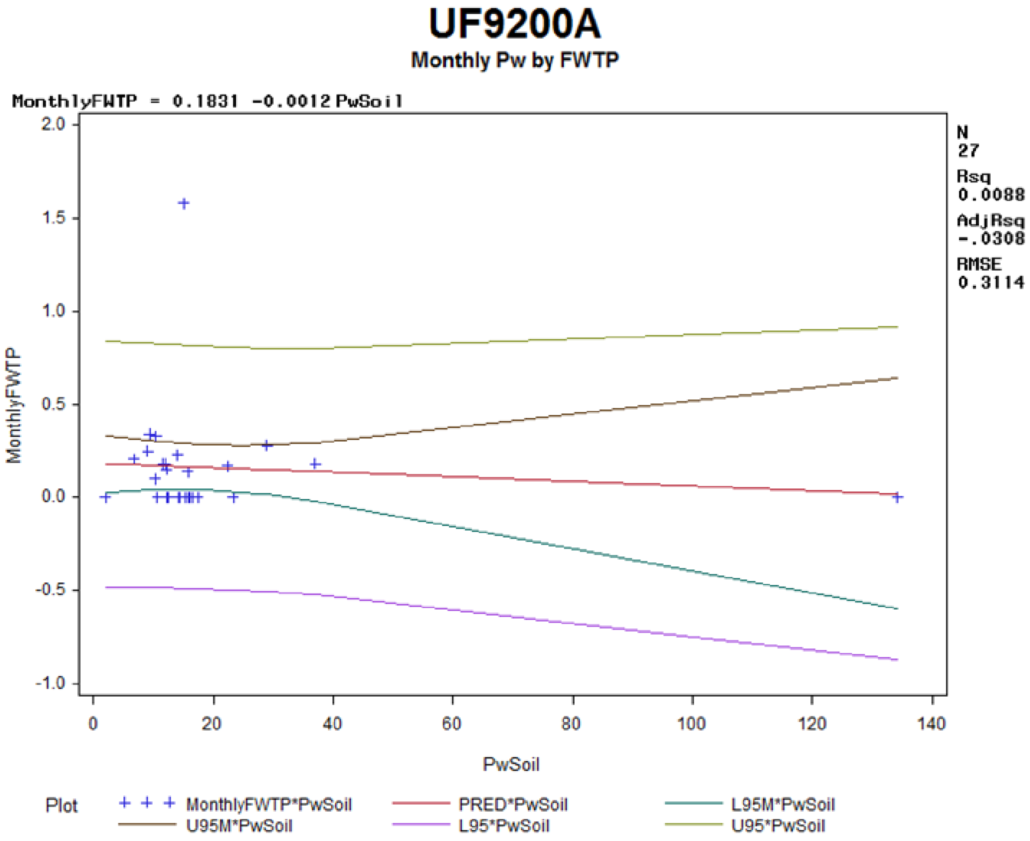


Figure 10. Scatter plot UF9200A

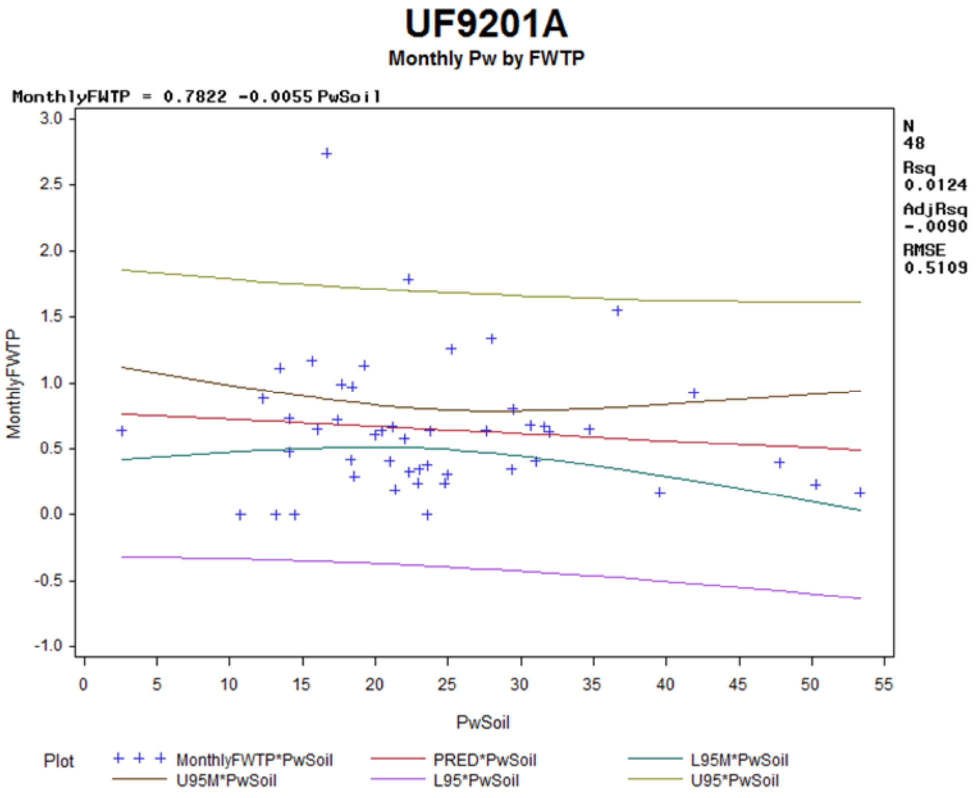


Figure 11. Scatter plot UF9201A

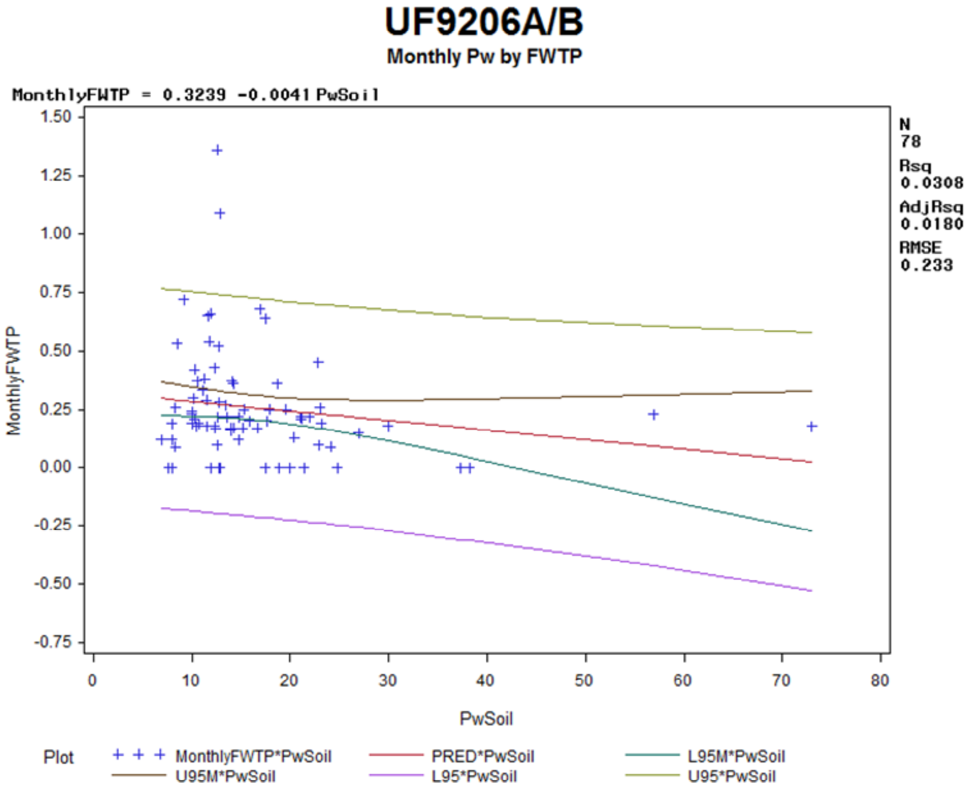


Figure 12. Scatter plot UF9206A/B

Table 1. Summary of Profile Characteristics of Histosols in the EAA

Soil series	Mineral content (%)	Thickness of organic layer (cm)	Underlying material	Proportion of agricultural area in 1988[a] (%)
Torry	>35	>130	Limestone	7
Terra Ceia	<35	>130	Limestone	9
Pahokee	<35	91-130	Limestone	27
Lauderhill	<35	51-91	Limestone	40
Dania	<35	<51	Limestone	10
Okeechobee	<35	>130[b]	Limestone	3
Okeelanta	<35	41-102	Sand	4

a USDA 1988
b Okeechobee is distinguished from Terra Ceia in that the former has subsurface layers of hemic materials
Source: Snyder, 1994

Table 2. Phosphorus solubilization rates of Florida’s organic soils

Soil	Initial amount of soil P available (ug/cm3 of soil	P leached into drainage water[a] (ug/cm3 of soil)	Final amount of soil P available (ug/m3 of soil)	P potentially solubilized (kg P ha-1)	P potentially solubilized (kg P ha-1 yr-1)
Cultivated soils					
F	11.3	25.2	8.5	22.4	149.6
D	16.8	10.2	17.3	10.7	71.5
C	8.8	23.3	15.2	29.7	105.4
A	7.3	9.7	2.6	5.0	33.9
BC	2.1	2.6	3.5	4.0	24.4
Virgin soils					
EV	8.7	23.9	12.6	27.8	185.7
BV	4.2	3.5	3.1	2.4	15.0

[a] Values shown are the total amounts of P leached after 350 days in soils A, C, D, EV and F, and 325 days for soils BC and BV, respectively.

A=Brighton; C=Lauderhill; D=Monteverde; EV=Monteverde (virgin); F=Oklawaha; BC=Pahokee; BV=Pahokee (virgin)

(Reddy, 1983)

Table 3. Summary statistics for three farms

UF Farm	Basin	Crops	Farm Size (hectares)	Farm Size Designation	Average Soil Depth (m)	Soil Depth Designation
UF9200A	S-5A	Sugarcane	518	Medium	1.16	Deep
UF9201A	S-6	Mixed	518	Medium	0.61	Shallow
UF9206A/B	S-5A	Mixed	710	Medium	0.88	Medium

Source: Daroub et al., 2007

Table 4. Descriptive statistics of monthly phosphorus loads (kg) on three EAA farms

	UF9200A	UF9201A	UF9206A/B
Mean	94.3	357.1	222.2
Median	43.9	124.3	108.7
Standard Deviation	164.0	543.4	347.5
Minimum	0.0	0.0	0.0
Maximum	1098.8	2527.9	2386.3

Source: Daroub et al., 2007

Table 5. Descriptive statistics of monthly soil phosphorus (mg/kg) on three EAA farms

	UF9200A	UF9201A	UF9206A/B
Mean	19.2	24.1	16.5
Median	14.1	22.3	13.6
Standard Deviation	24.0	10.3	10.1
Minimum	2.0	2.6	6.9
Maximum	134.3	53.3	73.0

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Appendix A

Monthly Average Soil Pw and Flow Weighted Total Phosphorus (FWTP) in Farm Discharge

Table A-1.. Monthly Average Soil Pw and Flow Weighted Total Phosphorus (FWTP) in Farm Discharge

Farm	Date	Average Pw (mg/kg)	Average TP in Discharge Water (mg/l)
UF9200A	10/1992	28.9	0.28
	02/1993	9.0	0.25
	01/1994	9.3	0.34
	02/1994	11.6	0.18
	03/1994	15.7	0.14
	01/1996	15.0	1.58
	02/1996	10.4	0.33
	03/1996	37.0	0.18
	02/1997	10.3	0.10
	02/1999	12.2	0.15
	01/2000	14.0	0.23
	03/2000	6.7	0.20
	02/2002	12.0	0.18
	03/2002	23.4	0.17
UF9201A	08/1992	15.6	1.17
	09/1992	14.1	0.48
	10/1992	18.5	0.29
	11/1992	16.0	0.65
	01/1993	30.7	0.68
	02/1993	50.3	0.23
	03/1993	53.3	0.17
	04/1993	29.4	0.35
	05/1993	34.7	0.65
	08/1993	12.3	0.88
	10/1993	21.0	0.41
	11/1993	22.3	1.79
	01/1994	28.0	1.34
	02/1994	25.2	1.26
	03/1994	24.9	0.31
	04/1994	18.3	0.42
	08/1994	13.2	0.00
	10/1994	21.2	0.67
	11/1994	13.5	1.11
	12/1994	18.4	0.97
	01/1995	20.0	0.61
	02/1995	31.9	0.63
	05/1995	23.6	0.38
	08/1995	19.3	1.13
	10/1995	23.8	0.73
	11/1995	14.1	0.92
	12/1995	41.9	0.48
	01/1996	39.6	0.17
	02/1996	24.8	0.24
	03/1996	23.0	0.35
	01/1997	2.6	0.64
	02/1997	20.5	0.64

Table A-1. Monthly Average Soil Pw and Flow Weighted Total Phosphorus (FWTP) in Farm Discharge (continued)

Farm	Date	Average Pw (mg/kg)	Average FWTP in Discharge Water (mg/l)
	03/1997	27.6	0.64
	11/1997	17.4	0.72
	01/1998	23.4	0.19
	02/1998	29.5	0.80
	03/1998	36.7	1.55
	04/1998	47.8	0.40
	05/1998	31.0	0.41
	12/1998	16.7	2.74
	01/1999	17.7	0.99
	02/1999	22.3	0.33
	03/1999	22.9	0.24
	04/1999	22.0	0.58
	05/1999	31.6	0.67
UF9206A/B	02/1993	21.2	0.21
	04/1993	14.3	0.17
	05/1993	27.0	0.15
	06/1993	20.4	0.13
	07/1993	22.9	0.10
	09/1993	19.6	0.25
	11/1993	11.3	0.38
	12/1993	14.1	0.37
	01/1995	8.3	0.26
	02/1995	13.6	0.22
	03/1995	15.2	0.17
	04/1995	11.7	0.65
	06/1995	18.7	0.36
	08/1995	22.9	0.45
	10/1995	10.1	0.30
	11/1995	12.9	1.09
	01/1996	12.8	0.28
	02/1996	13.9	0.17
	03/1996	10.3	0.42
	04/1996	12.8	0.52
	05/1996	9.2	0.72
	06/1996	17.5	0.64
	08/1996	12.6	0.22
	09/1996	11.5	0.29
	10/1996	10.7	0.19
	11/1996	10.3	0.21
	01/1997	10.0	0.24
	03/1997	8.0	0.12
	04/1997	14.8	0.12
	06/1997	24.1	0.09
	07/1997	8.3	0.09
	09/1997	14.7	0.22
	10/1997	11.5	0.18
	11/1997	10.0	0.23

Table A-1. Monthly Average Soil Pw and Flow Weighted Total Phosphorus (FWTP) in Farm Discharge (continued)

Farm	Date	Average Pw (mg/kg)	Average TP in Discharge Water (mg/l)
	12/1997	11.8	0.54
	02/1998	8.0	0.19
	03/1998	57.0	0.23
	04/1998	21.1	0.22
	11/1998	12.4	0.43
	01/1999	15.3	0.25
	05/1999	8.5	0.53
	06/1999	16.9	0.68
	07/1999	22.0	0.22
	08/1999	16.7	0.17
	09/1999	15.9	0.20
	10/1999	12.6	1.36
	11/1999	11.1	0.33
	12/1999	12.4	0.17
	01/2000	23.2	0.19
	02/2000	73.0	0.18
	03/2000	13.5	0.27
	04/2000	14.3	0.36
	07/2000	10.6	0.37
	08/2000	23.0	0.26
	09/2000	13.5	0.22
	10/2000	11.9	0.66
	03/2001	12.3	0.18
	04/2001	12.6	0.10
	07/2001	6.9	0.12
	08/2001	10.0	0.19
	09/2001	15.9	0.20
	10/2001	13.9	0.16
	11/2001	17.9	0.25
	12/2001	30.0	0.18
	01/2002	10.5	0.18
	02/2002	17.6	0.20