Agriculture, Ecosystems and Environment 138 (2010) 170–180

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Environmental and management factors that influence drainage water P loads from Everglades Agricultural Area farms of South Florida

Timothy A. Lang*, Olawale Oladeji, Manohardeep Josan, Samira Daroub

University of Florida, Institute of Food and Agricultural Sciences, Everglades Research and Education Center, 3200 E. Palm Beach Road, Belle Glade, FL 33430, USA

ARTICLE INFO

Article history:
Received 17 November 2009
Received in revised form 16 April 2010
Accepted 26 April 2010

Keywords:
Agricultural runoff
Best management practice
Histosol
Multiple linear regression
Phosphorus load
Principal Component Analysis

ABSTRACT

Environmental impacts from drainage water phosphorus (P) loads from Everglades Agricultural Area (EAA) farms in South Florida led to the adoption of best management practices (BMPs). The BMPs have been very successful at reducing EAA farm drainage water P loads. However, analytical investigation into how environmental and management factors affect farm P loading may allow additional improvements in BMP performance. Sixteen variables that included cropping systems, water management, and farm specific constants were hypothesized to affect farm P loads. Data collected from ten farms between 1992 and 2002 were analyzed using Spearman correlation, Principal Component Analysis, and stepwise multivariate regression. Monthly farm P load on a unit area basis (UAL) showed stronger correlation with drainage unit area volume (UAV) than with flow weighted total P concentration (FWTP). The UAL was negatively correlated with irrigation demand and positively correlated with irrigation P concentration, rainfall, preceding month's rain, drainage pumping to rainfall ratio, and percent fallow plus flooded field acreage (PFFA). A positive correlation between soil depth and FWTP was significant. Stepwise regression analysis identified canal water level management, percent sugarcane acreage, PFFA, and irrigation water P concentration as explanatory variables that impact farm P loads; PCA revealed similar results. The study suggests that lower pumping to rainfall ratio and increased sugarcane acreage lead to lower farm P loads; that irrigation water P concentration impacts farm P loads; and that shallower soils export less P than deeper soils.

1. Introduction

The Everglades Agricultural Area (EAA) in south Florida comprises 220,000 ha of cultivated Histosols with about 70% of the land farmed to sugarcane and lesser acreages to vegetables, sod, and rice (Rice et al., 2002b). The EAA is characterized by flat topography, shallow soils, seasonally elevated water tables, and an impermeable marl/limestone bedrock layer underlain by porous shellrock. During the dry season (November through May) and reduced rainfall periods, irrigation water is sourced from Lake Okeechobee to the north. During the wet season (June through October) and during wetter than normal dry seasons, excess precipitation must be pumped off farms to allow crop production. Farm drainage is achieved by pumping water from fields through a system of farm field ditches and farm canals via pump station(s) into conveyance canals that route the water south to Stormwater Treatment Areas (STAs, constructed wetlands) for phosphorus (P) removal via biofiltration and sequestration via sedimentation. Reduced P loads from the EAA to the STAs will enhance their outflow concentrations and increase their longevity (Pietro et al., 2009). Water from the STAs is sent to adjacent Water Conservation Areas (WCAs) where it replenishes groundwater and supplies water to the Everglades National Park to the south. The South Florida Water Management District (SFWMD) manages water quality, flows, and levels in the conveyance canals, STAs, and WCAs.

The EAA is dominated by Histosols (sub order: saprist) which are characterized by high soil organic matter content (>80%) that is highly decomposed (Snyder, 1994; Snyder and Davidson, 1994). The organic soils of the EAA differ mainly in the depth of the O horizon to the limestone bedrock (Rice et al., 2002a). Soils located close to the east and south shores of Lake Okeechobee (S5A and S6 sub-basins) are deeper, with depths greater than 1 m, while soils further south and east of the lake (S7 and S8 sub-basins) are shallower, i.e., less than 1 m (McCollum et al., 1978; Cox et al., 1988; Snyder, 2004). The EAA is located in a sub-tropical environment and has an average rainfall of 1.27 m year^{-1}. Distribution of the rainfall is, however, uneven with 66% occurring during the wet season, which lasts from June through October (Ali et al., 2000).

Phosphorus fertilization and soil organic matter oxidation (subsidence) are the two main sources of P exported from the EAA (Sanchez and Porter, 1994). Soil subsidence rates in the EAA have decreased from 3.00 cm year^{-1} in the 1940s and 1950s (Stephens

---

* Corresponding author. Tel.: +1 561 993 1500; fax: +1 561 993 1582.
E-mail address: talang@ufl.edu (T.A. Lang).

0167-8809/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2010.04.015

and Johnson, 1951) to 2.36 cm year^{-1} in the 1970s (Shih et al., 1978) to less than 1.45 cm year^{-1} in the 1990s (Shih et al., 1998). The decline in subsidence rate is thought to be due to higher water table management and decreases in the amount of readily oxidized organic matter (Shih et al., 1998). Non-point P loading (e.g. P from drainage of agricultural lands) is important because of its ecological impacts on freshwater and marine biota (House et al., 1995; Rabalais et al., 1996; Turner and Rabalais, 2003). Phosphorus is of particular concern because it has been implicated as the limiting nutrient in the eutrophication of lakes and wetlands in south Florida (Davis and Marshall, 1975; Federico et al., 1981). Phosphorus concentrations of more than 0.1 mg L^{-1} are high for freshwater bodies and detrimental to aquatic ecosystems (Correll, 1998; Downing et al., 2001). Phosphorus may be transported through the canal systems into Everglades wetlands, causing deterioration of water quality and alterations to the natural ecosystem (Wright and Reddy, 2001; Childers et al., 2003). Drainage, irrigation, rainfall, cropping systems, and other management factors can increase the potential for P movement into downstream ecosystems (Sharpley et al., 1994). Concerns regarding the impact of elevated P concentration drainage waters from the EAA on the Everglades ecosystem resulted in a regulatory program that requires annual EAA basin P loads to be reduced by at least 25% relative to historic levels (Everglades Forever Act, 1994).

To reduce farm P loads, growers in the EAA are required to adopt BMPs which have assigned points by the SFWMD; each grower's set of BMPs must add up to at least 25 points (Whalen and Whalen, 1996; Sievers et al., 2003; Daroub et al., 2004). Growers in EAA adopt similar sets of BMPs which typically include banding of P fertilizers, application of P fertilizers according to calibrated soil tests, avoiding drainage pumping until a pre-determined amount of rainfall has fallen, and implementing particulate matter control measures to reduce sediment export.

Since basin-wide BMP program implementation in 1995, the EAA basin has achieved an average P load reduction of 50% relative to the baseline period from 1978 to 1988 (Van Horn et al., 2009). The reported variability in sub basin and farm P loads despite 100% participation and implementation of similar BMPs by growers in the EAA since 1995 suggests that there are other factors that may be affecting EAA farm P loads besides those targeted by current BMPs (SFWMD, 2008). Numerous factors have been suggested to affect drainage P loads of EAA farms (Izuno and Rice, 1999). Using Seasonal Mann-Kendall analysis to determine long-term water quality trends in EAA drainage waters, Daroub et al. (2009) reported a decreasing trend in P loads from the outflows of the basin and two of its sub basins between 1992 and 2006. Differences in P load trends were noted within farms and sub-basins and were thought to be due to impact of irrigation water source, cropping systems, and flooding practices. It is not known, however, how these environmental, crop management, and site specific variables impact the individual farm P loads. Our goal was to use multivariate regression analysis to reveal the main factors affecting farm P loads using data collected during a long-term water quality study of ten EAA farms.

We hypothesized that EAA farm drainage water P load is affected by many variables including farm geographical location, irrigation water quality, farm size, soil depth, land use practices, and farm water management. The specific objectives of the study were to (1) evaluate relationships between farm P load and cropping systems, water management, and farm specific variables; and (2) investigate

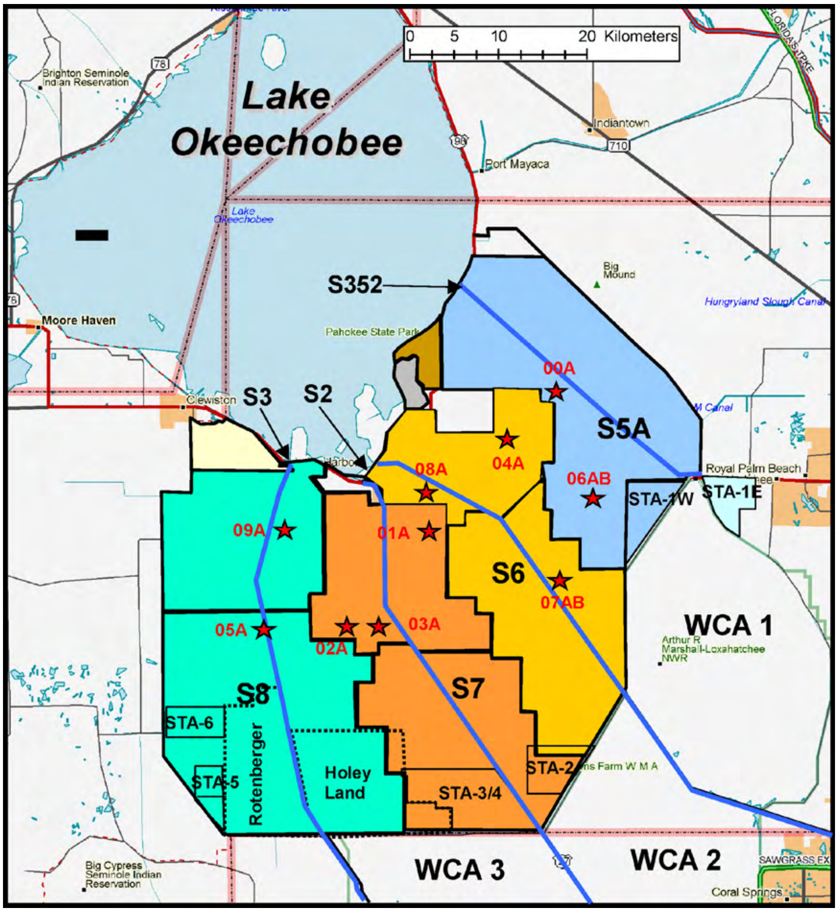

Fig. 1. Location of the ten farms (indicated by red stars), sub-basins (S5A, S6, S7, and S8), and irrigation inflow structures from Lake Okeechobee (S352, S2, S3) in the Everglades Agricultural Area in south Florida. Water Conservation Areas (WCAs) and Stormwater Treatment Areas (STAs) are also indicated on the map.

Table 1
Selected monthly parameters at the ten farms between August 1992 through December 2002.

Parameter	Farm ID									
	00A	01A	02A	03A	04A	05A	06AB	07AB	08A	09A
Basin	S5A	S6	S7	S7	S6	S8	S5A	S6	S6	S8
Crop	Sugarcane	Mixed	Sugarcane	Sugarcane	Sugarcane	Mixed	Mixed	Mixed	Sugarcane	Sugarcane
Percent cane (% of farm)	95.0 ± 0.8[d]	0.0 ± 0.0	96.8 ± 1.1	87.1 ± 0.6	90.7 ± 2.3	70.8 ± 1.9	34.9 ± 0.7	74.4 ± 1.1	78.9 ± 3.9	95.1 ± 0.7
Soil depth (m)	1.16	0.61	0.46	0.43	1.62	0.55	0.88	0.98	0.73	0.98
Farm size (ha)	518	518	129	1865	259	129	710	1012	106	1243
Inside Head, AMSL[a] (m)	2.47 ± 0.02	2.53 ± 0.02	3.23 ± 0.02	2.49 ± 0.02	2.54 ± 0.02	2.63 ± 0.02	1.80 ± 0.04	2.36 ± 0.02	2.63 ± 0.07	2.21 ± 0.02
Outside Head, AMSL (m)	3.08 ± 0.03	3.46 ± 0.06	3.43 ± 0.03	3.30 ± 0.03	3.19 ± 0.02	3.11 ± 0.01	2.97 ± 0.05	3.33 ± 0.03	2.56 ± 0.08	3.07 ± 0.01
Head difference (m)	0.61 ± 0.03	0.93 ± 0.07	0.20 ± 0.02	0.81 ± 0.03	0.64 ± 0.02	0.48 ± 0.02	1.16 ± 0.03	0.97 ± 0.03	-0.07 ± 0.04	0.86 ± 0.02
Rainfall (mm)	131 ± 10	98 ± 10	154 ± 10	114 ± 8	135 ± 10	118 ± 11	125 ± 8	116 ± 8	143 ± 11	109 ± 8
Drainage volume ($\times 10^5$ m^3)	3.37 ± 0.37	4.25 ± 0.63	0.80 ± 0.11	6.01 ± 0.65	1.00 ± 0.12	1.76 ± 0.22	6.68 ± 0.57	6.76 ± 0.69	0.39 ± 0.04	6.20 ± 0.54
Pumping: Rainfall (mm:mm)	0.50 ± 0.05	1.13 ± 0.20	0.37 ± 0.04	0.30 ± 0.04	0.28 ± 0.03	1.20 ± 0.15	0.75 ± 0.05	0.61 ± 0.08	0.41 ± 0.09	0.54 ± 0.08
Irrigation P (mg L^{-1})	0.17 ± 0.01	0.12 ± 0.01	0.13 ± 0.01	0.12 ± 0.01	0.12 ± 0.01	0.07 ± 0.00	0.16 ± 0.01	0.12 ± 0.01	0.13 ± 0.01	0.08 ± 0.00
Irrigation P load (kg ha^{-1})	0.08 ± 0.02	0.10 ± 0.02	0.06 ± 0.02	0.06 ± 0.01	0.08 ± 0.02	0.05 ± 0.01	0.10 ± 0.01	0.07 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
Irrigation Demand (mm)	36.3 ± 5.2	62.3 ± 6.9	24.9 ± 5.0	49.5 ± 5.0	40.0 ± 5.7	55.1 ± 6.6	46.2 ± 5.0	43.5 ± 5.0	34.9 ± 5.9	50.6 ± 5.0
Flow Weighted TP (mg L^{-1})	0.26 ± 0.02	0.75 ± 0.06	0.08 ± 0.01	0.14 ± 0.01	0.18 ± 0.01	0.09 ± 0.01	0.30 ± 0.02	0.27 ± 0.02	0.09 ± 0.01	0.09 ± 0.01
UAV[b] (m^3 drainage ha^{-1})	650 ± 72	820 ± 121	617 ± 83	322 ± 35	385 ± 45	1357 ± 173	941 ± 80	668 ± 68	367 ± 38	499 ± 44
UAL[c] (kg P ha^{-1})	0.18 ± 0.04	0.69 ± 0.13	0.06 ± 0.01	0.04 ± 0.00	0.07 ± 0.01	0.12 ± 0.02	0.31 ± 0.05	0.16 ± 0.02	0.03 ± 0.00	0.04 ± 0.00

[a] Above mean sea level.
[b] Unit Area Volume.
[c] Unit Area Load.
[d] Mean of monthly data ± standard error.

possible predictive equations that relate farm P load to environmental, geophysical, and land use characteristics of farm basins. The study is intended to provide researchers, water managers, regulators, and growers with a more complete understanding of the factors affecting EAA farm P loading and assist in attaining additional reductions in farm P loads.

2. Materials and methods

2.1. Study area

The EAA comprises a flat landscape of organic soils (Histosols) that is underlain by limestone bedrock and has been actively drained since the early 1920s (Snyder, 2005; Rice et al., 2002b). To sustain productivity, growers in the EAA drain their fields via an extensive array of canals, ditches, and large volume, low lift, pumps into SFWMD conveyance canals, which transport the water downstream to STAs for P removal via biofiltration and sequestration. The EAA basin is divided hydrologically into four sub-basins, S5A, S6, S7, and S8 (Fig. 1). The four sub-basins correspond to outflow structures that line the south and east periphery of the EAA basin. Each sub-basin is also associated with a main conveyance canal that transects each sub-basin. The S-5A sub-basin contains the West Palm Beach Canal, the S-6 sub-basin contains the Hillsboro canal, the S-7 sub-basin contains the North New River Canal, and the S-8 sub-basin contains the Miami Canal. These sub-basins have been shown to vary greatly with regard to their respective P load exports (SFWMD, 2008).

The majority of data used in the study were collected from a long term BMP efficacy study that involved monitoring ten EAA farms' P related parameters and farm specific variables for seven to ten years (Daroub et al., 2004). Each of the ten farms was given a unique farm ID: 00A, 01A, 02A, 03A, 04A, 05A, 06A/B, 07A/B, 08A, 09A respectively (Fig. 1). Two farms (00A and 06A/B) are located in the S-5A sub-basin; four farms (01A, 04A, 07A/B. and 08A) are located in the S-6 sub-basin, two farms (02A and 03A) are in the S-7 sub-basin; and two farms (05A and 09A) are in the S-8 sub-basin (Fig. 1). Six farms (00A, 02A, 03A, 04A, 08A, 09A) were predominantly sugarcane farms; four farms (01A, 05A, 06A/B, 07A/B) cultivated multiple crops included sugarcane, vegetables, and sod (Daroub et al., 2004). The six sugarcane farms had more than 85% of the farm acreage planted to sugarcane in most years. One exception was farm basin 08A which switched from being predominantly sugarcane monoculture from 1992–1999 to 55% and 29% of the acreage planted to vegetables in 2000 and 2001, respectively. The remaining four farms had mixed-cropping systems: farm 01A was strictly vegetable monoculture; farm 05A was planted to sugarcane, sod, and melons; farm 06A/B was planted to sugarcane, vegetables, rice, sod and trees; and farm 07A/B grew sugarcane, vegetables, rice and sod (Table 1).

The ten farms represent a range of EAA sugarcane-vegetable-rice-sod cropping systems, farm sizes, drainage capacities, soil depths, and hence adequately represent the population of EAA farm basins. Farm basins in the EAA select and implement similar BMPs—improved handling and spill prevention practices, modified application methods, calibrated soil testing, rainfall detention, and sediment controls (Table 2). This suite of BMPs were employed on the ten farm monitored farms with only minor differences (Daroub et al., 2004).

2.2. Data collection

Monitoring of drainage volumes, P concentrations, P loads, and twelve other related parameters of the ten farm basins began in July 1992 and lasted between 7 and 10 year. The datasets were summarized into monthly time intervals for use in the statistical analyses. Seven of the ten farms have data for the complete ten year monitoring period which is continuous from August 1992 through December 2002. Two of the remaining farms (01A and 05A) have continuous data from August 1992 through December 1999. One farm (08A) has continuous data from August 1992 through August 2001. Drainage water samples, collected by autosampler that were triggered by datalogger wired to drainage pumps, were digested via mercuric oxide procedure (Method 365.4, USEPA, 1983) and analyzed for P using a Flow IV segmented flow analyzer (OI Analytical, College Station, TX). Farm rainfall was measured via tipping bucket rain gauge connected to datalogger. Lag rain was defined as the previous month's rainfall. Detailed descriptions of farm variables and data collection can be found in Daroub et al. (2009).

To account for the differences in farm areas on the estimated P load, unit area P load (UAL) in kg P ha^{-1} was obtained by dividing the farm P load by farm area. Similarly, unit area drainage water volume (UAV) in m^3 ha^{-1} was obtained by dividing monthly drainage water volume (m^3) of each farm by farm-area (ha). The

Table 2
Best management practices and assigned points for EAA[a] basin farms.

BMP	PTS	Description	
Nutrient control		Minimize movement of nutrients off-site	
Nutrient Application Control	2.5	Controlled application of nutrients; banding; fertigation	
Nutrient Spill Prevention	2.5	Formal spill prevention protocols	
Plant Tissue Analysis	2.5	Determines plant nutrient requirements next growing season (crop specific)	
Calibrated Soil Testing	5	Determine the P requirements of the soil and follow standard recommendations for application rates	
Water management		Minimize volume of off-site discharges	
1/2 Inch Detained	5	Delay discharge based on measuring daily rain events using a rain gauge	
1 inch Detained	10		
Improved Water Management Infrastructure	5	Re-circulate water inside farm boundaries prior to offsite discharge; rice and fallow flood waters not direct discharged off-farm; increased water detention using properly constructed canal berms.	
Particulate matter		Minimize movement of particulat matter and sediments	
Any 2	2.5	Leveling fields	Barriers at discharge locations
		Slow drainage velocity near pumps	Ditch bank stabilization
Any 4	5	Grassed swales	Sediment sump/trap in canals
		Vegetated ditch banks	Culvert bottoms above ditch bottoms
Any 6	10	Ditch bank berms	Cover crops
		Canal cleaning program	Field ditch drainage sumps
Any 8	15	Aquatic weed control	

[a] For the EAA basin, a minimum of 25 points is required for each farm's BMP plan.

product of UAV and FWTP is equivalent to the UAL for each farm basin.

Irrigation water P concentration data were obtained for the EAA basin inflow structures from SFWMD DBHYDRO (http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu) database for the period of 1992–2002. Basin inflow water TP data were obtained for the three inflow structures into the EAA (S352, S2, and S3). The West Palm Beach Canal (sub basin S-5A) received irrigation water from structure S352 while farms linked with North New River (Sub basin S7) and Hillsboro (sub basin S-6) canals received irrigation from structure S2. The S8 sub basin received irrigation water from structure S3 via the Miami canal (Fig. 1). Irrigation demand was calculated as the difference of monthly evaporation data from the Belle Glade, Florida weather station evaporation pan and an individual farm's monthly rainfall. Surface ditch irrigation to manipulate field water table is the predominant method used to irrigate crops in the EAA (Izuno, 1994). Irrigation P load was estimated as the product of irrigation demand, irrigation P concentration, and a surface ditch irrigation use efficiency of 50% (Jones et al., 1984; Omary and Izuno, 1995).

Percent farm acreages occupied by sugarcane, rotational flood, and fallow plus flood were determined from monthly crop maps that had delineated crops by field. Interpolated crop acreages were substituted for missing monthly data according to standard harvest and planting schedules. The percent fallow plus flood acreage (PFFA) was included as a single variable in the data set, since the crop mapping personnel often had difficulty making definitive determinations on flooding or fallow condition for fields that were often intermittently flooded.

2.3. Statistical data analysis

Monthly UAV, FWTP, and UAL data were not normally distributed. Box-Cox transformations (Box and Cox, 1964) were used to stabilize the variance, and make the residuals Gaussian distributed for regression analyses. Spearman correlation, stepwise multivariate regression analysis, and Principal Component Analysis (PCA) were employed to determine farm P load variable relationships. Stepwise regression was conducted to identify measured variables that could account for drainage water volume, P loads, and P concentrations. Stepwise regression is not recommended for testing the significance of a variable, but it is a convenient procedure for selecting variables when a large number of variables are considered, as in this study. Stepwise regression was conducted for all ten farms (pooled data), the six sugarcane farms, four mixed-crop farms, and for each individual farm. Regression analysis was conducted on Box-Cox transformed UAL, UAV, and FWTP data (dependent variables) using PROC REG in SAS (SAS Institute, 2006), and all statistical tests were conducted at $\alpha = 0.05$ significance level. A PCA was performed using PROC PRINCOMP in SAS (SAS Institute, 2006) to identify principal trends in explanatory variables. The PCA is widely applied in exploratory data analysis and for generating predictive models. The PCA mean centers the data for each attribute and then computes eigenvalue decomposition (or singular value decomposition) of a dataset. Principal components with eigenvalue greater than 1 were retained as suggested in Kaiser's rule (Kaiser, 1960, 1961). The Kaiser's rule ensure that any component that accounts for less variance than does a single variable is dropped. The rule has been widely used as criteria to decide on PC to retain in PCA analysis (Jackson, 1993; Jolliffe, 2002; Peres-Neto et al., 2005), and using same rule, as much PC to explain between 70 and 90% of population variance were identified in this study.

3. Results and discussion

3.1. Environmental parameters and management factors

Monthly averages of the measured variables are shown in Table 1. Average farm soil depths ranged from 0.43 m at farm 03A to 1.62 m at farm 04A. Soil depth varies considerably across the EAA, and generally decreases with distance from Lake Okeechobee. A comprehensive soil survey of the organic soils of Palm Beach County conducted in 1988 indicated that the S-5A sub-basin

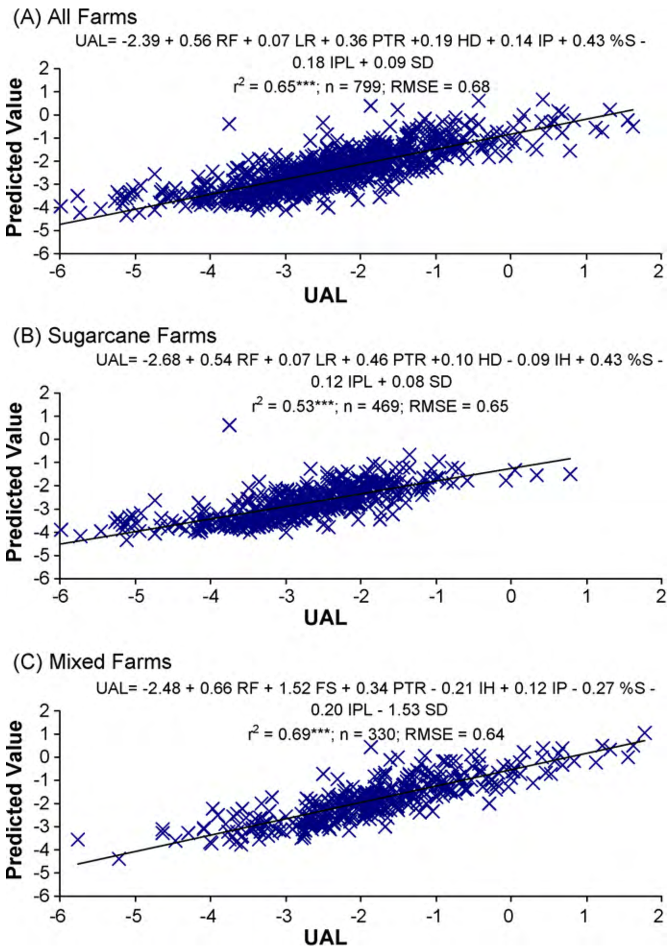

Fig. 2. Regression of Box-Cox transformed unit area P load (UAL) and the predicted values for the pooled ten farms. (RF = rainfall; LR = lag rain; PTR = pump to rainfall ratio; HD = head difference; IP = irrigation P concentrations; IPL = irrigation P loads; SD = soil depth).

has the deepest soils, while the S-7 and S-8 sub-basins have the shallowest soils (Cox et al., 1988). Farms with deeper soils are able to hold more water on farm without detriment to crops and are able to reduce the frequency of drainage. Thus, deeper soils can lower drainage volumes, resulting in lower P loadings. Farms with shallow soils have less capacity to hold water on farm. The reduced water holding capacity requires them to drain more frequently to successfully farm. However, the greater interaction of drainage water with fragments of limestone ($CaCO_3$) cap rock and marl on shallow soils may increase the probability that soluble P is removed from the soil water through sorption/precipitation processes, offsetting increases in P loading due to increased drainage requirements (Murphy et al., 1983; Diaz et al., 1994).

The ten farms ranged in size from 106 to 1865 ha. Even though the drainage volume and the P load were normalized with farm area to obtain UAV and UAL, smaller farms would seem to be more susceptible to seepage from surrounding farms and adjoining water conveyance canals. Depending upon the elevation of surrounding canals and farms, there could be high drainage UAV with resultant high UAL in small farms (e.g. farms 02A, 04A, 05A, and 08A). In addition, small farms may not have the flexibility of storing water on farm and may have less capacity to adjust field water tables across the farm. A farm's canal head difference (difference between outside and inside canal water levels) can serve as index of drainage requirement and may indicate a farm's elevation relative to drainage and seepage in its location. Maintenance of a high head difference should require more drainage volume to maintain the head difference. Mean head difference ranged from −0.07 m in farm 08A to 1.16 m in farm 06AB.

Mean monthly rainfall ranged from a low of 98 mm at 01A to 154 mm at 02A. Pumping to rainfall ratio ranged from a low of 0.28 at farm 04A to a high of 1.2 in farm 05A (Table 1). Six of the farms (00A, 02A, 03A, 04A, 08A, and 09A) had a PTR ratio of less than 0.5, and the remaining four farms (01A, 05A, 06A/B, and 07A/B) had PTR ratio greater than 0.5. Lowest PTR ratio was observed at farm 08A, a small sugarcane farm (106 ha) located in the S6 sub-basin with an average soil depth of 0.73 m. Excluding farm 05A, which appeared to have seepage from the adjacent Miami canal and a high PTR ratio of 1.20, the two farms that had the highest PTR ratio were farm 01A (PTR = 0.68) and farm 06A/B (PTR = 0.73). Farm 01A is strictly a vegetable farm in the S6 sub-basin with an average soil depth of 0.60 m and farm 06A/B is a mixed crop farm located in the S5A sub-basin with an average soil depth of 0.88 m. Research has shown that sugarcane can maintain optimum yields through a wide range of water tables (Glaz et al., 2004b) and cultivars with constitutive aerenchyma are able to tolerate flooded conditions for at least 1 week with minimal effect on yield (Glaz et al., 2004a). The leafy vegetables grown in the EAA are water sensitive and cannot tolerate flooding or high water tables (Snyder et al., 1978; Snyder, 1987). Percentage sugarcane cropped, and inside/outside canal heads for the different farms are also reported in Table 1.

Mean monthly UAV ($m^3\,ha^{-1}$) values of the ten farms ranged from 322 $m^3\,ha^{-1}$ in farm 03A to 1357 $m^3\,ha^{-1}$ in farm 05A (Table 1). Cropping systems can also affect UAV; for example, the four farms (01A, 05A, 06A/B, and 07A/B) that show greatest UAV have mixed-cropping systems, which are less tolerant to flooding, and require more drainage pumping than sugarcane farms.

The FWTP ranged from less than 0.26 $mg\,L^{-1}$ in the sugarcane farms to 0.75 $mg\,L^{-1}$ in mixed cropping farms. Four farms (02A, 05A, 08A, and 09A), had a mean annual FWTP of less than 0.10 $mg\,L^{-1}$. All of these farms were sugarcane farms except for 05A. Four farms (00A, 03A, 04A 06A/B, and 07A/B) had mean FWTP greater than 0.10, but less than 0.30 $mg\,L^{-1}$. The higher P concentrations in farms 01A (0.75 $mg\,P\,L^{-1}$) and 06A/B (0.30 $mg\,P\,L^{-1}$) reflect the higher P fertilizer rates required for vegetables and other crops compared to sugarcane (Hochmuth et al., 2003; Gilbert and Rice, 2006). By comparison, annual FWTP concentrations from the EAA basin between 1994 and 2005 ranged from a high of 0.130 $mg\,L^{-1}$ in 1995 to a low of 0.069 $mg\,L^{-1}$ in 2003 (Adorisio et al., 2006).

The UAL also reflects impacts of cropping. Except for farm 00A (0.18 $kg\,P\,ha^{-1}$ UAL), sugarcane farms (02A, 03A, 04A, 08A, and 09A) had less than 0.07 $kg\,P\,ha^{-1}$ UAL. Impacts of these environmental and management variables on farm UAL are discussed in detail in the next sections.

3.2. Relationships between parameters and factors

Simple correlation analysis can be used to identify the important variables that may potentially be used to model farm P loads. Spearman correlation analysis results showed that UAL correlated with thirteen of the fifteen environmental and farm management factors shown in Table 3. Even though UAL was calculated as product of both FWTP and UAV, UAL showed a stronger correlation with UAV ($r = 0.86^{***}$) than with FWTP ($r = 0.52^{***}$). This suggests a greater effect of UAV than FWTP on UAL. The strong relationship between UAL and UAV is further explained by the similarities in how the other variables correlated with each of them. Both UAL and UAV correlated with most of the variables measured. Both UAL and UAV showed negative correlation with irrigation demand, and positive correlation with irrigation P concentration. Both UAL and UAV also showed positive correlations with rainfall, lag rainfall, PTR, and PFFA. Rainfall and lag rainfall are expected to increase the UAV, and hence UAL, and help explain the observed positive cor-

Table 3
Spearman correlation coefficients of monthly variables collected from the ten farms between 1992 and 2002.

Variable[a]	UAL[b]	FWTP	UAV	MIH	MOH	MHD	PTR	PSA	PFFA	Rainfall	ID	IPC	IPL	Soil depth	Farm size
FWTP	0.52***														
UAV	0.86***	0.05^{ns}													
MIH	−0.22***	−0.24***	−0.13***												
MOH	0.04^{ns}	0.12***	−0.01^{ns}	0.44***											
MHD	0.25***	0.34***	0.11***	−0.54***	0.52***										
PTR	0.66***	0.04^{ns}	0.73***	−0.19***	0.02^{ns}	0.20***									
PSA	−0.45***	−0.52***	−0.21***	0.30***	−0.03^{ns}	−0.32***	−0.32***								
PFFA	0.24***	0.24***	0.13***	−0.01^{ns}	0.02^{ns}	0.02^{ns}	0.14***	−0.53***							
Rainfall	0.52***	0.00^{ns}	0.64***	0.08*	−0.07*	−0.14***	0.03^{ns}	0.07^{ns}	0.02^{ns}						
ID	−0.53***	0.01^{ns}	−0.65***	−0.06^{ns}	0.04^{ns}	0.10**	−0.12***	−0.08*	−0.02^{ns}	−0.91***					
IPC	0.23***	0.22***	0.16***	−0.08*	−0.00^{ns}	0.07*	−0.05^{ns}	−0.08*	−0.11*	0.17***	−0.22***				
IPL	−0.45***	0.00^{ns}	−0.53***	−0.03^{ns}	0.03^{ns}	0.06^{ns}	−0.12***	−0.07*	0.01^{ns}	−0.73***	0.85***	0.20***			
SD	0.01^{ns}	0.21***	−0.06^{ns}	−0.22***	−0.09*	0.12***	−0.10**	0.21***	−0.20***	0.03^{ns}	−0.04^{ns}	0.12**	−0.01^{ns}		
Farm Size	−0.11**	0.00^{ns}	−−0.13***	−0.28***	0.16***	0.42***	−0.10**	0.14***	−0.12***	−0.10**	0.10**	−0.07^{ns}	0.06^{ns}	−0.23***	
Lag Rain	0.14***	−0.03^{ns}	0.19***	0.03^{ns}	−0.09*	−0.11**	0.10**	0.09**	−0.01^{ns}	0.19***	−0.19***	0.01^{ns}	−0.02^{ns}	0.04^{ns}	−.10**

ns = non-significant at 0.05 *P* value.

[a] Number of observations per variable: $n = 809$.

[b] UAL = Unit Area Load; FWTP = Flow-Weighted Total P; MIH = Monthly Inside Head; MOH = Monthly Outside Head; MHD = Monthly Head Difference; PTR = Pump to Rain Ratio; PSA = Percent Sugarcane Acreage (% of farm); PFFA = Percent Fallow + Flood acreage (% of farm); ID = Irrigation Demand; IPC = Irrigation P Concentration; IPL = Irrigation P Load; SD = Soil Depth.

[*] Significant at the 0.05 *P* value.

[**] Significant at 0.01 *P* value.

[***] Significant at 0.001 *P* value.

relation between rainfall related parameters and UAL. The positive correlation between UAL and PTR confirms that reducing pumping volumes can lower farm P loads. Two variables that did not show significant correlation with UAL and UAV are soil depth and outside head difference; interestingly however, soil depth did correlate with FWTP.

The UAL was positively correlated with irrigation P concentration, but negatively correlated with irrigation demand and irrigation P load. Irrigation demand is directly linked to rainfall; as irrigation demand increases drainage pumping decreases and results in low monthly P load. This relationship explains the negative correlation between UAL and both irrigation demand and irrigation P load. The FWTP was positively correlated with irrigation water P concentration, but not with rainfall, irrigation demand, and irrigation P load. This correlation indicates irrigation water quality may impact farm drainage water P concentration.

Negative correlations of PSA acreage with UAL, UAV, and FWTP are consistent with minimal drainage volume and lower P loads that are expected from sugarcane farms than from other mixed cropping farms. Sugarcane generally receives applications of 20–50 kg P ha^{-1} year^{-1} compared to vegetable crops, such as lettuce, corn, and green beans which may receive 150 kg P ha^{-1} year^{-1} or more (Gilbert and Rice, 2006; Hochmuth et al., 2003).

3.3. *Parameter and factor impacts on farm P loads*

Since many of the variables correlated well with P load, stepwise regression was conducted to explain which factors most affected farm UAL, UAV, and FWTP. Variables identified by stepwise regression that affect UAL, UAV and FWTP are reported in Table 4. Pumping to rainfall ratio was a significant variable in all the regression equations. Other variables that were shown to affect UAL, UAV, and FWTP are canal head difference and irrigation P concentration. The relationship between canal head difference and UAL indicates that greater canal head difference was associated with higher UAL. Two of these variables (PTR and canal head difference) are water management variables and point to the importance of water management to reduce UAL. A recent study used three different Classification and Regression Trees (CART) models (single regression trees, committee trees in Bagging, and ARCing modes) to investigate the relationship between environmental factors and P loads in the same ten EAA farms (Grunwald et al., 2009). Tree-based models are distribution free (non-parametric) and make no assumptions about regression variables of residuals (Breiman et al., 1984). Multivariate regression models used in the current study are parametric, and data was transformed to establish normal distribution. However, results reported in the current study are in agreement with Grunwald et al. (2009), which indicated that hydrologic/water management properties are the major controlling factors affecting UAL in the EAA.

Irrigation water P concentration is equally important in the farm UAL regression equations. The regression analysis revealed that irrigation P concentration and irrigation demand loads are important in explaining farm P load. Irrigation water quality may be negatively impacting farm P load, particularly on sugarcane farms in the S5A sub basin. The three main inflow structures supplying irrigation water differed in the quality of the irrigation water they supplied. Of the three structures, the S-352, which supplies irrigation water to farms in the S-5A sub-basin via the West Palm Beach Canal, delivered water with the highest P concentration from 1992 through 2002. In addition farm drainage water P concentrations tended to be grouped into two distinctive areas. Drainage water from farms in S-5A and S-6 sub-basins showed greater P concentrations than from the S-7 and S-8 sub-basins (Table 1). Positive regression coefficients suggest increased UAL with increases in irrigation water P concentration. Irrigation water for EAA farms

Table 4
Coefficients of variables selected by stepwise regression that significantly affect P load, volume, or P concentration of monthly drainage water collected between 1992 and 2002.

Dependent variable[a,b]	No. of obs. (n)	Regression coefficients of the independent variables											Coefficient of determination (r^2)[c]
		Intercept	MIH (m)	MHD (m)	Soil depth	Percent sugarcane	Rainfall	Pump to rain ratio	Lag rainfall	Irrigation P conc.	Irrigation P load	Farm size	
All ten farms													
UAL	799	−2.39	–	0.19	0.09	−0.43	0.56	0.36	0.08	0.14	−0.18	–	0.65^{***}
UAV	799	14.9	−0.87	1.09	−0.80	–	4.07	3.05	0.29	0.46	−1.03	−0.99	0.72^{***}
FWTP	799	−2.39	0.18	0.12	0.48	−0.82	–	−0.13	–	0.17	–	0.22	0.43^{***}
Six cane farms													
UAL	469	−2.68	−0.09	0.10	0.08	–	0.54	0.46	0.07	0.16	−0.12	–	0.53^{***}
UAV	469	14.3	−0.58	0.49	–	–	3.85	3.49	0.38	0.54	–	–	0.64^{***}
FWTP	469	−3.04	0.19	–	0.50	−0.22	–	−0.15	–	0.24	−0.89	0.28	0.23^{***}
Four mixed-crop farms													
UAL	330	−2.48	−0.21	–	−1.53	−0.27	0.66	0.34	–	0.12	−0.20	1.52	0.69^{***}
UAV	330	16.0	–	0.69	–	–	4.40	2.74	0.51	0.91	−1.28	−1.49	0.78^{***}
FWTP	330	−2.37	−0.13	–	−2.06	−0.65	0.10	−0.10	–	–	–	2.70	0.64^{***}

[a] Unit Area P Load, kg P ha^{-1} (Box-Cox transformed); Unit Area Drainage Volume, m^3 ha^{-1} (Box-Cox transformed); Flow Weighted P Concentration, mg P L^{-1} (Box-Cox transformed).

[b] MIH = Monthly Inside Canal Head, MHD = Monthly Canal Head Difference.

[c] Significant regression coefficient of determination (r^2) at P value = 0.001.

originates from Lake Okeechobee. Thus, efforts to reduce lake water P concentrations will complement farmers' efforts to reduce farm P loads. The finding adds additional weight for the need to decrease P levels in Lake Okeechobee.

The effect of soil depth was significant on the UAL prediction equations for the pooled farms and six sugarcane farms and indicated that deeper soils have the potential to produce higher farm UAL. The soil depth results are based on the ten farm dataset and may not necessarily hold true for other EAA farms. However, this analysis gives us an initial reference and suggests that soil depth does affect P load. Specific management practices that target deeper soils, e.g. higher water tables, are needed to offset soil depth effects on UAL.

Crop rotation also affects farm UAL. It is evident from the regression equations that UAL has an inverse relationship with PSA; as PSA increased, UAL decreased. This finding is not surprising given the higher P fertilizer requirement and more intensive water management that crops besides sugarcane need. An earlier study (CH2MHill, 1978) reported greater P concentrations in drainage water from vegetable farms (0.340 mg L^{-1},) than from a sugarcane farm (0.126 mg L^{-1}) in the EAA.

The relationship between flooding and UAL is not entirely clear, because the effect of flooding could not be separated from fallowing as earlier explained. It may be an indication that changes in land use (less sugarcane acres and increases in other crop acres) might increase farm P loads. This indicates a need for further investigation on the impact of flooding on farm UAL.

Stepwise regression of UAL with the variables was also conducted for each individual farm to further reduce the confounding effects in the model. However, the results obtained (data not shown) were similar to the pooled data and emphasized the impacts of pumping, rainfall, and irrigation P on farm P loads. A related study using tree-based CART models to investigate factors affecting P load also suggested significant impacts of water managements on P loads (Grunwald et al., 2009).

3.4. Principal Component Analysis

There were relatively few strong correlations among the 13 variables tested. Thus, Principal Component Analysis (PCA) was used to account for the correlations between the explanatory variables. The PCA is a powerful statistical technique that can transform a large number of correlated variables into a smaller number of uncorrelated variables called principal components (PC) (Laaksoharju et al., 1999). The PCA derives linear combinations (as PC) of a set of variables that retain as much of the information in the original variables as possible. The PCA technique can identify and reduce dimensionality of dataset, determine meaningful underlying variables, and minimize the effect of scatters on output (Smith, 2002). The PCA has been extensively used on water quality datasets (Kim et al., 2000; Simeonov et al., 2003; Chen et al., 2007; Halim et al., 2008), and is also widely applied in exploratory data analysis and for generating predictive models.

The PCA results including the loadings and eigenvalue of each PC are summarized in Tables 5 and 6, and Table 7 for the pooled (ten) farms, the sugarcane farms, and the mixed farms. There are several criteria to identify the number of PCs to be retained in order to understand the underlying data structure (Jackson, 1991). A commonly used rule is to retain PCs with eigenvalue greater than 1 and as such generally can account for 70–90% of the variance. Thus, in this study, PCs with eigenvalue greater than 1 were retained, and six independent PCs were extracted by PCA for each of the three datasets (pooled, sugarcane, and mixed farms). The retained PCs explained 78, 80, and 84% of the total population variance of the pooled, sugarcane, and mixed farms, respectively (Tables 5–7). This percentage can be considered large enough to give an ade-

Table 5
The loadings of each variable, the Eigenvalue, and description for each of the six principal components obtained from principal component analysis of monthly UAL of the ten farms.

Variables	Principal components[a]					
	PC1	PC2	PC3	PC4	PC5	PC6
Inside Canal Head	**−0.36**[b]	−0.27	0.14	**0.54**	0.22	−0.07
Outside Canal Head	0.17	0.11	−0.08	**0.64**	**0.44**	0.01
Canal Head Difference	**0.50**	**0.37**	−0.21	0.08	0.21	0.08
Lag Rainfall	−0.08	−0.13	0.00	−0.14	0.20	**0.79**
Farm Size	0.24	**0.45**	−0.07	0.23	**−0.38**	0.19
Soil Depth	−0.07	0.27	0.18	**−0.39**	**0.39**	−0.05
Irrigation Demand	**0.33**	−0.14	**0.57**	0.11	−0.24	−0.05
Irrigation P Load	**0.33**	−0.05	**0.61**	−0.00	0.07	0.04
Irrigation P	0.07	0.09	0.10	−0.21	**0.52**	**−0.31**
Pumping: Rainfall Ratio	0.22	**−0.38**	0.05	−0.04	0.20	**0.41**
Percent Sugarcane	**−0.44**	**0.36**	0.28	0.13	−0.06	0.19
Percent Fallow + Flood	0.20	**−0.46**	**−0.33**	−0.01	−0.07	−0.14
Eigenvalue	2.18	1.72	1.62	1.57	1.22	1.07
Eigenvalue Difference	0.46	0.09	0.06	0.34	0.15	N/A
% Variance explained	18	13	14	13	10	9
% Cumulative Variance	18	32	46	59	69	78
Description	Water Status	Cropping Practices	Irrigation water	Seepage Potential	Farm Specific constants	Pumping Index

[a] Eigenvalue greater than 1.
[b] Values in bold have absolute values greater than 0.3 and are considered to have influence on the principal component.

quate representation of the data. Also, the PCA was able to reduce the 16 variables to 6 for the pooled dataset and each of the farm types.

The first component (PC1) has the highest eigenvalue and explains the largest percentage of variance. Later components have lower eigenvalue and explain lower percentages of variance. For all ten farms, PCA analysis show that PC1 explains 18% of the total variance, and was heavily influenced by irrigation demand, canal head difference, and PSA, all of which are related to the field water status. Component 2 (PC2) explains 13% of the total variance and was related to land use variables such as PFFA, PSA, farm size, canal elevation difference. Component 3 (PC3) was related to irrigation water demand and quality and explained 14% of the total variance. Component 4 (PC4) which contrasts canal elevations with soil depth can be described as a measure of seepage potential. Component 5 and 6 (PC5 and PC6) explained 10% and 9% of total variance and were retained because they both have sufficient eigenvalue (greater than 1). The PC5 contrasts farm size with soil depth and also account for outside canal head and irrigation P concentration while PC6 accounts for rainfall and pumping. The PCA of variables from sugarcane and mixed farms differed little from the pooled data and also summarized the variables into six principal components (Tables 6 and 7). The cumulative variance explained by the PCs increased from 78% (for the pooled data) to 80% (for sugarcane) and 84% (for mixed farms). By categorizing the farms into sugarcane and mixed farms, we only improved the variance accounted by 2 and 6% respectively compared to the pooled data. The cumulative variance explained by the PCs increased from 78% (for the pooled data) to 80% (for sugarcane) and 84% (for mixed farms).

Regression equations using the Principal Component Regression (PCR) analysis were compared to stepwise multivariate regression equations (Figs. 2 and 3). The PCs were not reduced (for the pooled data) as we had hoped, which made the interpretations of the PC analysis complicated. However, the variables were reduced to 5 and 4 for the sugarcane farms and the mixed farms respectively (Fig. 3). Nevertheless, the PCA regression analysis results were in

Table 6
The loadings of each variable, the Eigenvalue, and description for each of the six principal components obtained from principal component analysis of monthly UAL of the six sugarcane farms.

Variables	Principal components[a]					
	PC1	PC2	PC3	PC4	PC5	PC6
Inside Canal Head	−0.29	**0.42**[b]	0.07	**0.48**	0.11	−0.0
Outside Canal Head	**0.30**	**0.42**	−0.10	0.29	**0.43**	−0.02
Canal Head Difference	**0.58**	−0.03	−0.16	−0.16	**0.33**	−0.02
Lag Rainfall	−0.13	0.06	0.11	−0.06	0.04	**0.83**
Farm Size	**0.53**	−0.12	−0.24	0.20	−0.18	0.08
Soil Depth	−0.08	0.02	0.18	**−0.66**	**0.32**	−0.19
Irrigation Demand	**0.32**	−0.07	**0.59**	0.09	−0.20	−0.08
Irrigation P Load	0.19	0.04	**0.69**	0.11	0.01	0.03
Irrigation P	−0.17	0.22	0.15	0.03	**0.41**	−0.24
Pumping: Rainfall Ratio	0.08	−0.14	0.06	−0.09	**0.43**	**0.44**
Percent Sugarcane	0.10	**0.53**	−0.05	−0.29	**−0.30**	0.07
Percent Fallow + Flood	−0.11	**−0.52**	0.00	0.28	0.28	−0.08
Eigenvalue	2.26	2.05	1.67	1.46	1.14	1.03
Eigenvalue Difference	0.21	0.39	0.21	0.32	0.11	N/A
% Variance explained	19	17	14	12	10	8
% Cumulative Variance	19	36	50	62	72	80
Description	Water Status	Cropping Practices	Irrigation water	Seepage Potential	Farm Specific constants	Pumping Index

[a] Eigenvalue greater than 1.
[b] Values in bold have absolute values greater than 0.3 and are considered to have influence on the principal component.

Table 7
The loadings of each variable, the Eigenvalue, and description for each of the six principal components obtained from principal component analysis of monthly UAL of the four mixed farms.

Variables	Principal components[a]					
	PC1	PC2	PC3	PC4	PC5	PC6
Inside Canal Head	−**0.40**[b]	−0.08	0.06	**0.45**	0.14	0.08
Outside Canal Head	−0.05	0.07	**0.50**	**0.57**	0.23	0.09
Canal Head Difference	**0.37**	0.16	**0.44**	0.10	0.08	−0.01
Lag Rainfall	−0.02	−0.02	0.04	−**0.36**	**0.67**	−**0.43**
Farm Size	**0.48**	−0.04	0.05	0.19	0.11	0.18
Soil Depth	**0.52**	−0.11	−0.08	0.13	0.14	0.14
Irrigation Demand	−0.07	**0.53**	−**0.36**	0.29	−0.06	0.18
Irrigation P Load	0.07	**0.61**	−0.27	0.12	0.11	0.15
Irrigation P	**0.32**	0.21	0.06	−0.20	−0.11	−**0.49**
Pumping: Rainfall Ratio	−0.15	0.22	−0.01	−0.18	**0.58**	−0.52
Percent Sugarcane	0.03	−**0.42**	−**0.42**	0.28	0.25	−0.04
Percent Fallow + Flood	−0.25	0.16	**0.41**	−0.19	−0.13	−**0.43**
Eigenvalue	3.11	1.88	1.65	1.49	1.19	1.00
Eigenvalue Difference	1.23	0.23	0.15	0.31	0.34	N/A
% Variance explained	26	15	14	12	10	7
% Cumulative Variance	26	41	55	67	77	84
Description	Farm Specific constants	Irrigation water	Cropping Practices	Seepage Potential	Pumping Index	Flooding Status

[a] Eigenvalue greater than 1.

[b] Values in bold have absolute values greater than 0.3 and are considered to have influence on the principal component.

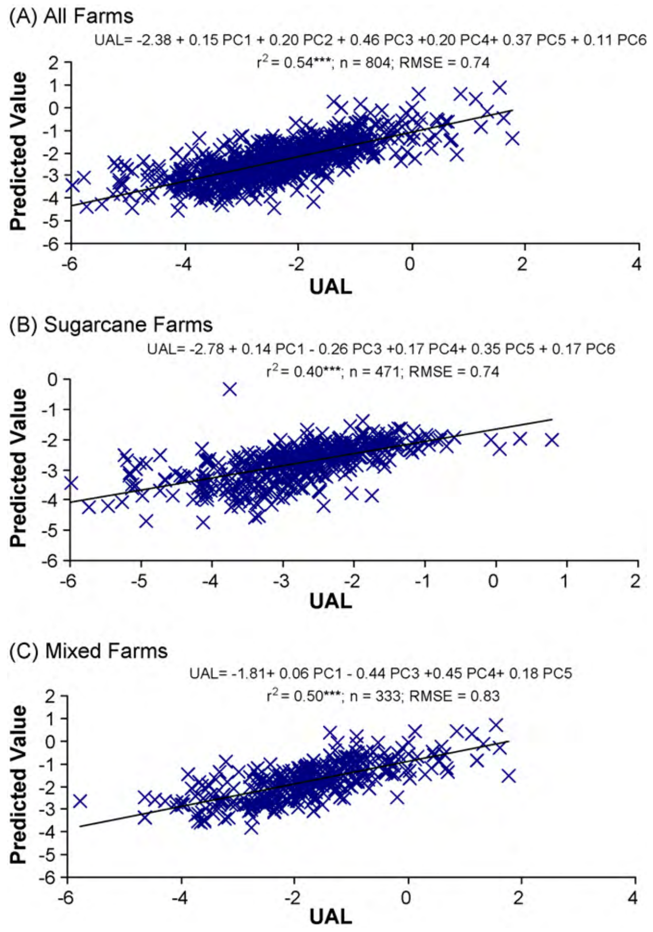

Fig. 3. Regression of Box-Cox transformed drainage water unit area P load (UAL) and the predicted values (by principal components 1–6) for the (A) ten farms, (B) sugarcane farms, and (C) mixed farms. PC1, PC2, PC3, PC4, PC5, and PC6 are Principal component 1, 2, 3, 4, 5, and 6 respectively (see Tables 4–6 for descriptions of the principal components).

agreement with the multivariate linear regression in identifying factors affecting P loading.

4. Conclusions

Analysis of the long-term monitoring datasets of ten EAA farms revealed insight on environmental and management variables that affect farm P loading. Though a myriad of factors were surmised to affect farm P loads, specific factors were identified that impact farm P loading. Water management variables (PTR, IPL, IPC, rainfall, lag Rainfall) were the dominant factors affecting UAL.

Management of these impact factors to improve BMP performance on EAA farms is expected. For example, lowering drainage volume (and pumping to rainfall ratio) may be achieved by improving internal drainage within a farm. Drainage volume reductions are accomplished by installing water control structures (culverts with riser boards) and land leveling. Water control improvements reduce total drainage water discharge volume by eliminating the need to over drain portions of a farm to adequately drain low lying sections and by reducing the need to over irrigate to adequately supply water to higher sections of a farm. The installation of improvements (ditch deepening, canal cleaning, culvert installation, booster pumps, etc.) may temporarily suspend sediments and increase loading for the next few drainage events. However, after these initial spikes in drainage water P loads, the improved control of water within the farm should result in decreased farm P loads and improved crop production. The results of this study show that additional farm P load reductions may be achieved with improved water management; that increased P concentrations in irrigation water are of concern for EAA drainage water quality; and that water management research that targets farms with deeper soils is recommended to achieve additional P load reductions.

Acknowledgements

This project was funded by the Everglades Agricultural Area Environmental Protection District. The collaboration and cooperation of the growers in the Everglades Agricultural Area is greatly appreciated. Support in the form of data, as noted from the

South Florida Water Management District, is duly appreciated. This project was also supported by the Florida Agricultural Experiment Station.

References

Adorisio, C., Bedregal, C., Daroub, S.H., DeLeon, J., Edwards, M., Garvey, C., Madden, J., McGinnes, P., Miessau, C., Pescatore, D., Sievers, P., Van Horn, S., Van Veen, T., Vega, J., Xue, S.K., Zhao, H., 2006. Chapter 3: phosphorus controls for the basins tributary to the Everglades protection area. In: South Florida Environmental Report, South Florida Water Management District. West Palm Beach, FL, USA. Available at http://my.sfwmd.gov/pls/portal/docs/PAGE/PG_GRP_SFWMD_SFER/PORTLET_PREVREPORT/2006_SFER/VOLUME1/chapters/v1_ch_3.pdf (verified 08 April 2010).

Ali, A., Abtew, W., Van Horn, S., Khanal, N., 2000. Temporal and spatial characterization of rainfall over central and south Florida. J. Am. Water Res. Assoc. 36, 833–848.

Box, G.E.P., Cox, D.R., 1964. An analysis of transformations. J. Royal Stat. Soc., Series B 26, 211–252.

Breiman, L., Friedman, J.H., Olsen, R.A., Stone, C.J., 1984. Classification and Regression Trees. Wadsworth International Group, CA, 358pp.

CH2M Hill, 1978. Water quality studies in the Everglades Agricultural Area of Florida. CH2M Hill, Gainesville, FL.

Chen, K., Jiao, J.J., Huang, J., Huang, R., 2007. Multivariate statistical evaluation of trace elements in groundwater in a coastal area in Shenzhen, China. Environ. Poll. 147, 771–780.

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

Correll, D.L., 1998. The role of phosphorus in the eutrophication of receiving waters: A review. J. Environ. Qual. 27, 261–266.

Cox, S., Lewis, D., McCollum, S., Bledsoe, M., Marrotte, R., 1988. Subsidence study of the Everglades Agricultural Area. USDA, Soil Conservation Service, Greenacres, FL.

Daroub, S.H., Lang, T.A., Diaz, O.A., Grunwald, S., 2009. Long-term water quality trends after implementing best management practices in South Florida. J. Environ. Qual. 38, 1683–1693.

Daroub, S.H., Lang, T.A., Diaz, O.A., Chen, M., Stuck, J.D., 2004. Annual report phase XII: implementation and verification of BMPs for reducing P loading in the EAA and Everglades Agricultural Area BMPs for reducing particulate phosphorus transport. Submitted to the Everglades Agricultural Area Environmental Protection District and The Florida Department of Environmental Protection. Univ. of Florida, Everglades Research and Education Center, Belle Glade, FL.

Davis, F.E., Marshall, M.M., 1975. Chemical and biological investigations of Lake Okeechobee January 1973-June 1974. Technical Publication 75-1, South Florida Water Management District, West Palm Beach, Florida.

Diaz, O.A., Reddy, K.R., Moore, P.A., 1994. Solubility of inorganic phosphorus in stream water as influenced by pH and calcium concentration. Water Res. 28, 1755–1763.

Downing, J.A., Watson, S.B., McCauley, E., 2001. Predicting Cyanobacteria dominance in lakes. Can. J. Fish. Aquat. Sci. 58, 1905–1908.

Everglades Forever Act, 1994. The Everglades Forever Act. Amending the Marjory Stoneman Douglas Everglades Protection Act. Florida Statute Section 373.4592.

Federico, A., Dickson, K., Kratzer, C., Davis, F., 1981. Lake Okeechobee water quality studies and eutrophication assessment. Technical Publication 81-2, South Florida Water Management District, West Palm Beach, Florida.

Gilbert, R.A., Rice, R.W., 2006. Nutrient requirements for sugarcane production on Florida muck soils. UF-IFAS SS-AGR-226, Gainesville, FL.

Glaz, B., Morris, D.R., Daroub, S.H., 2004a. Periodic flooding and water table effects on two sugarcane genotypes. Agron. J. 96, 832–838.

Glaz, B., Morris, D.R., Daroub, S.H., 2004b. Sugarcane photosynthesis, transpiration, and stomatal conductance due to flooding and water table. Crop Sci. 44, 1633–1641.

Grunwald, S., Daroub, S.H., Lang, T.A., Diaz, O.A., 2009. Tree-based modeling of complex interactions of phosphorus loadings and environmental factors. Sci. Total Environ. 407, 3772–3783.

Halim, M.A., Majumder, R.K., Nessa, S.A., Oda, K., Hiroshiro, Y., Saha, B.B., Hassain, S.M., Latif, S.K.A., Islam, M.A., Jinno, K., 2008. Groundwater contamination with arsenic in Sherajdikhan, Bangladesh: Geochemical and hydrological implications. Environ. Geol. 58, 73–84.

Hochmuth, G., Hanlon, E.A., Snyder, G.H., Nagata, R., Schuenemann, T., 2003. Fertilization of sweet corn, celery, romaine, escarole, endive, and radish on organic soils in Florida. UF-IFAS Bull. 313, Gainesville, FL.

House, W.A., Denison, F.H., Armitage, P.D., 1995. Comparison of the uptake of inorganic phosphorus to a suspended and stream bed-sediment. Water Res. 29, 767–779.

Izuno, F.T., 1994. Physical components and water management in the Lake Okeechobee-EAA-WCA-ENP system. In: Bottcher, A.B., Izuno, F.T. (Eds.), Everglades Agricultural Area (EAA): Water, Soil, Crop, and Environmental Management. University Press of Florida, Gainesville, FL, pp. 85–153, Chapter 6.

Izuno, F.T., Rice, R.W., 1999. Implementation and verification of BMPs for reducing P loading in the EAA. Final Project Report submitted to the Florida Department of Environmental Protection and the Everglades Agricultural Area Environmental Protection District, Tallahassee, FL.

Jackson, J.E., 1991. A User Guide to Principal Components. Wiley, New York.

Jackson, D.A., 1993. Stopping rules in principal components analysis: A comparison of heuristical and statistical approaches. Ecology 74, 2204–2214.

Jolliffe, I.T., 2002. Principal Component Analysis. Springer, New York.

Jones, J.W., Allen, L.H., Shih, S.F., Rogers, J.S., Hammond, L.C., Smajstrla, A.G., Martsolf, J.D., 1984. Estimated and measured evapotranspiration for Florida climate, crops, and soils. IFAS Univ. of Florida Cooperative Extension Service, Bulletin 840.

Kaiser, H.F., 1960. The application of electronic computers to factor analysis. Educ. Psych. Measur. 20, 141–151.

Kaiser, H.F., 1961. A note on Guttman's lower bound for the number of common factors. Br. J. Math. Stat. Psych. 14, 1–2.

Kim, M.J., Nriagu, J., Haack, S., 2000. Carbonate ions and arsenic dissolution by groundwater. Environ. Sci. Technol. 34, 3094–3100.

Laaksoharju, M., Skarman, C., Skarman, E., 1999. Multivariate mixing and mass balance (M3) calculation, a new tool for decoding hydrogeochemical information. Appl. Geochem. 14, 861–871.

McCollum, S.H., Cruz, E., Stem, L.T., Wittstruck, W.H., Ford, R.D., Watts, F.C., 1978. Soil survey of Palm Beach County area, Florida. USDA/NRCS in cooperation with Univ. of Florida Agric. Exp. Stations, Gainesville, FL.

Murphy, T., Hall, K., Yasaki, I., 1983. Coprecipitation of phosphate and calcite in naturally eutrophic lake. Limnol. Oceanogr. 28, 28–67.

Omary, M., Izuno, F.T., 1995. Evaluation of sugarcane evapotranspiration from water table data in the Everglades Agricultural Area. Agric. Water Manage. 27, 309–319.

Peres-Neto, P.R., Jackson, D.A., Somers, K.M., 2005. How many principal components? Stopping rules for determining the number of non-trivial axes revisited. Comput. Stat. Data Anal. 49, 974–997.

Pietro, K., Bearzotti, R., Germain, G., Iricanin, N., 2009. Chapter 5: STA Performance, Compliance and Optimization. In: South Florida Environmental Report 2009, South Florida Water Management District. West Palm Beach, FL, USA. Available at http://my.sfwmd.gov/portal/page/portal/pg_grp_sfwmd_sfer/portlet_sfer/tab2236041/2009report/report/v1/chapters/v1_ch5.pdf (verified 08 April 2010).

Rabalais, N.N., Turner, G.A., Dortch, Q., Wiseman Jr., W.J., Gupta, B.K.S., 1996. Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. Estuaries 19, 386–407.

Rice, R.W., Gilbert, R.A., Daroub, S.H., 2002a. Application of the soil taxonomy key to the organic soils of the Everglades Agricultural Area. EDIS document # SS-AGR-246, Florida Coop. Ext. Service, Inst. of Food and Agric. Sci., Univ. of Florida, Gainesville, FL.

Rice, R.W., Izuno, F.T., Garcia, R.M., 2002b. Phosphorus load reductions under best management practices for sugarcane cropping systems in the Everglades Agricultural Area. Agric. Water Manage. 56, 17–39.

Sanchez, C.A., Porter, P.S., 1994. Phosphorus in the organic soils of the EAA. In: Bottcher, A.B., Izuno, F.T. (Eds.), Everglades Agricultural Area (EAA): Water, Soil, Crop, and Environmental Management. University Press of Florida, Gainesville, FL, pp. 62–80, Chapter 5.

SAS Institute, 2006. *OnlineDoc*. Version 9.1. SAS Inst., Cary, NC.

Sharpley, A.N., Chapra, S.C., Wedepohl, R., Sims, J.T., Daniel, T.C., Reddy, K.R., 1994. Managing agricultural phosphorus for protection of surface waters: Issues and options. J. Environ. Qual. 23, 437–451.

Shih, S.F., Glaz, B., Barnes, R.E., 1998. Subsidence of organic soils in the Everglades Agricultural Area during the past 19 years. Soil Crop Sci. Soc. Florida Proc. 57, 20–29.

Shih, S.F., Stewart, E.H., Allen Jr., L.H., Hilliard, J.W., 1978. Variability of depth to bedrock in Everglades organic soil. Soil Crop Soc. Florida Proc. 38, 66–71.

Sievers, P., Pescatore, D., Daroub, S., Stuck, J.D., Vega, J., McGinnes, P., Van Horn, S., 2003. Chapter 3. Performance and optimization of agricultural best management practices. In: Everglades Consolidated Report, Water Year 2002, South Florida Water Management District, West Palm Beach, FL. Available at: http://my.sfwmd.gov/pls/portal/docs/PAGE/PG_GRP_SFWMD_SFER/PORTLET_PREVREPORT/ECR2003/chapters/ch3.pdf (verified 03 August 2009).

Simeonov, V., Stratis, J.A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Sofoniou, M., Kouimtzis, T.H., 2003. Assessment of surface water quality in Northern Greece. Water Res. 37, 4119–4124.

Smith, L., 2002. A Tutorial on Principal Components Analysis, Vol. 51. Cornell University, USA, pp. 52.

Snyder, G.H., 1987. Agricultural flooding of organic soils. Tech. Bull. 870. Agr. Exp. Station, Inst. Food and Agr. Sciences, Univ. Florida, Gainesville, Fl.

Snyder, G.H., Davidson, J.M., 1994. Everglades agriculture: past, present, and future. In: Davis, S.M., Ogden, J.C. (Eds.), Everglades, the Ecosystem and its Restoration. St Lucie Press, Boca Raton, FL, pp. 85–115.

Snyder, G.H., 1994. Soils of the EAA. In: Bottcher, A.B., Izuno, F.T. (Eds.), Everglades Agricultural Area (EAA): Water, Soil, Crop, and Environmental Management. University Press of Florida, Gainesville, FL, pp. 27–41, Chapter 3.

Snyder, G.H., 2004. Everglades Agricultural Area soil subsidence and land use projections. 2004. Prepared for the South Florida Water Manage. Dist., West Palm Beach, FL. Available at: http://www.evergladesplan.org/pm/projects/project_docs/pdp_08_eaa_store/pdp_08_sub_land_use_report.pdf (verified 08 April 2010).

Snyder, G.H., 2005. Everglades Agricultural Area soil subsidence and land use projections. Soil Crop Sci. Soc. Florida Proc. 64, 44–51.

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

South Florida Water Management District, 2008. Final Report: final analysis EAA basin data evaluation (Phase II). South Florida Water Management District, West Palm Beach, Florida, USA.

Stephens, J.C., Johnson, L., 1951. Subsidence of organic soils in the upper Everglades. Soil Crop Sci. Soc. Florida Proc. 11, 191–237.

Turner, R.E., Rabalais, N.N., 2003. Linking landscape and water quality in the Mississippi River Basin for 200 years. Bioscience 53, 563–572.

USEPA, 1983. Methods for chemical analysis of water and wastes. U.S. Environmental Protection Agency, Environ. Monitoring and Support Lab., Cinncinnati, OH, USA.

Van Horn, S., Adorisio, C., Bedregal, C., Gomez, J., Gornak, S., Madden, J., Pescatore, D., Sarley, S., Rucks, C., Wade, P., 2009. Chapter 4: Phosphorus source controls for the south Florida environment. In: South Florida Environmental Report 2009, South Florida Water Management District, West Palm Beach, FL. Available at: http://my.sfwmd.gov/portal/page/portal/pg_grp_sfwmd_sfer/portlet_sfer/tab2236041/2009report/report/v1/chapters/v1_ch4.pdf (verified 08 April 2010).

Whalen, P.J., Whalen, B.M., 1996. Non-point Source Best Management Practices Program for the Everglades Agricultural Area. Paper no. 96-2071, American Society of Agricultural Engineering, ASAE, St. Joseph, MI.

Wright, A.L., Reddy, K.R., 2001. Heterotrophic microbial activity in northern Everglades wetland soils. Soil Sci. Soc. Am. J. 65, 1856–1864.