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Nutrients in a Playa Wetland Receiving Wastewater

T. P. Pezzolesi, R. E. Zartman,[*] E. B. Fish, and M. G. Hickey

ABSTRACT

We determined nutrient sequestration differences in soil and vegetation within two regions of a playa wetland that receives agricultural runoff and secondarily treated wastewater. Playas are small, topographically closed, ephemeral wetlands that serve as catchments for surface runoff in the Southern High Plains of the USA. The wetland studied received natural runoff and secondarily treated wastewater from the U.S. Department of Energy, Pantex facility near Amarillo, TX. Soil and aboveground biomass N, P, Cu, and Fe and water N and P were evaluated seven times during a 2-yr period in cattail (*Typha domingensis* Pers.) and pink smartweed [*Persicaria pensylvanica* (Raf.) Nieuw.] dominated regions of the playa. Spatial and temporal variabilities were observed in water, vegetation, and soil-nutrient concentrations. These variabilities were likely due to fluctuation of water depth and quality in the playa. Water was deeper ($P <$ 0.05) in the cattail region compared with the smartweed region. Water quality [Total Kjeldahl N (TKN) and total P (TP)] was not effected ($P >$ 0.05) by vegetation type. Soil concentrations of TKN, TP, Cu, and Fe were not significantly different ($P >$ 0.05) between cattail and smartweed vegetative types. Cattail had significantly greater ($P <$ 0.05) levels of TKN, TP, Cu, and Fe than did smartweed. Aboveground biomass was greatest in August. Based on nutrient sequestration this playa wetland functioned quite well as a receptor for added nutrients from runoff and the wastewater treatment facility.

WETLANDS are recognized vital natural resources that may be harmed by nonpoint source pollution. Many wetlands bioaccumulate nutrients and chemical contaminants from runoff and wastewaters (Lewis, 1995). Wetlands have also been used as filtering areas for sediment and nutrient contaminants (Lowrance et al., 1985, Altier et al., 1997). Besides bioaccumulation and filtration, wetland vegetation provides a substrate for the attachment of decomposer microorganisms (Spangler, 1976). Prentki et al. (1978) showed that the net effect of rooted emergent vegetation in a cattail (*Typha domingensis* Pers.) marsh was transfer of nutrients from the soil to the water. However, algae obtain nutrients from water and transfer nutrients to the soil via detritus (Vymazal, 1995).

On the Southern High Plains, there are thousands of shallow, circular wetlands known as playas. With playa wetlands now thought to be the areas of focused recharge for the Ogallala aquifer, playa water quality is an important consideration (Zartman et al., 1994, Gustavson et al., 1995). Wetland surface areas average 6.3 ha in size and occupy approximately 3% of the total surface area (Bolen et al., 1989). Basin depressions range from several centimeters to 20 m below the outerbasin soils (Traweek, 1981).

Wetlands are accepted as nonpoint treatment facilities and are likely to continue (Marble, 1992). Since at least 1972, some playas were used, and continue to be used, for runoff catchment from cattle feedlots (Lehman, 1972). Stewart et al. (1994) reported N and P data from playas storing beef feedlot and dairy lot wastes. Total soil N in the top 30 cm ranged from 3000 to 4000

T P Pezzolesi and R E Zartman, Dep of Plant and Soil Science, and E B Fish, Dep of Range, Wildlife, and Fisheries Management, Texas Tech Univ , Lubbock, TX 79409; and M G Hickey, M,H Consulting, Lubbock, TX Texas Tech Journal Article no T-4-417 [*]Corresponding author (zrich@ttacs ttu edu)

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Abbreviations: TKN, total Kjeldahl nitrogen, TP, total phosphorus, *P*, probability, SEM, standard error of the mean

Table 1. Average water depth as a function of time and location at the Pantex DOE facility during 1992 and 1993. Means were compared using paired *t*-tests.

	Sampling date						
	May 1992	July 1992	Aug. 1992	Nov. 1992	May 1993	July 1993	Aug. 1993
				Cattail			
No. of samples	6	8	8	8	5	6	8
Water depth, mm	76	178	80	84	54	98	96
				Smartweed			
No. of samples	2	8	5	8	4	6	7
Water depth, mm	5	92	26	41	23	44	55
$P > F$	0.016	0.021	0.020	0.017	0.071	0.171	0.032

mg kg^{-1} for beef and dairy lots. They also reported soil P of the top 30 cm to be 2000 mg kg^{-1} for the beef and dairy lots (Stewart et al., 1994). Haukos and Smith (1996) reported soil concentrations to be approximately 168 mg kg^{-1} TKN and 28 mg kg^{-1} EDTA-extractable P for eight Southern High Plains playas that are not used as feedlot runoff catchment areas.

Currently there are concerns with the use of playa wetlands for wastewater treatment practices (A.E. Fryar and W.F. Mullican III, 1995, unpublished report). In the Texas Panhandle, approximately 30 playas are used for municipal wastewater treatment (T. Nisbet, 1993, personal communication). One such playa is at the Pantex facility, U.S. Department of Energy, near Amarillo, TX. Pantex first produced ammunition for World War II and currently disassembles the U.S. nuclear arsenal (R.H. Ramsey III, K.A. Rainwater, and T.R. Mollhagen, 1995, unpublished report). High explosives produced for conventional weapons and those such as High Melting Explosive used to implode nuclear weapons contain high amounts of nitrogenous compounds. Those high N wastes are transmitted to the wetland via the waste treatment facility (Ramsey et al., 1995).

The objectives of this study were to determine differences in soil and vegetation associated with contrasting nutrient sequestration between cattail and smartweed dominated areas of a playa wetland that received agricultural runoff and secondarily treated wastewater at the U.S. Department of Energy, Pantex facility.

MATERIALS AND METHODS

The playa wetland was at the U.S. Department of Energy, Pantex facility in Carson County, Texas, approximately 27 km northeast of Amarillo. The playa basin soil was classified as

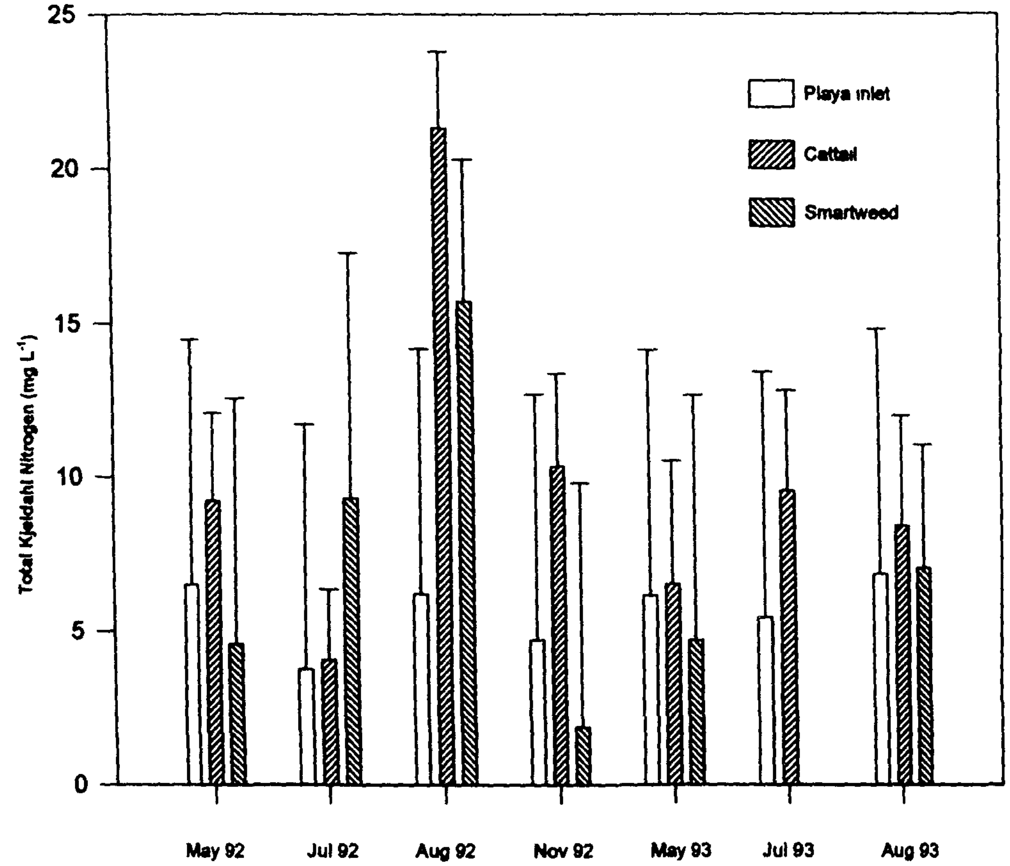

Fig. 1. Water total Kjeldahl N (+1 SEM) by location at the Pantex DOE facility playa wetland during 1992 and 1993.

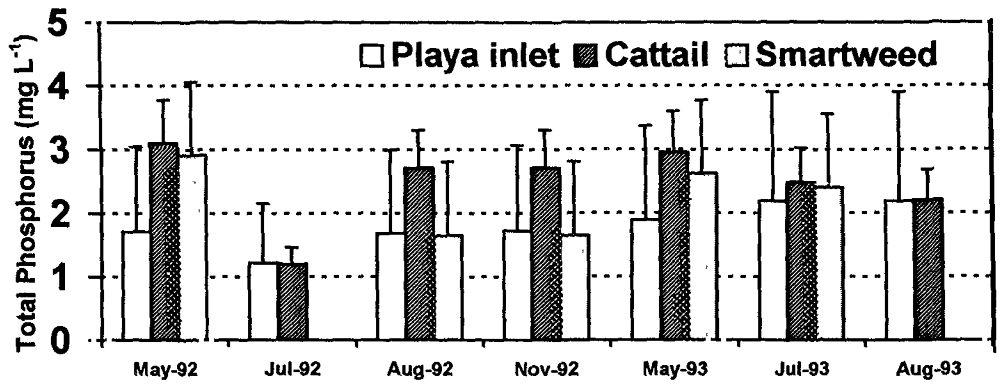

Fig. 2. Water total P (+1 SEM) by location at the Pantex DOE facility playa wetland during 1992 and 1993.

a Randall clay (fine, smectitic, thermic Ustic Epiaquerts) and occupied an estimated 37 ha in a 1069-ha rangeland–cropland watershed of flat topography. Hydrologic characteristics of the playa, particularly runoff, vary annually with precipitation and wastewater additions. Average annual Carson County precipitation is 560 mm and varies from 250 to 1070 mm with most of the runoff in late spring or summer (Jacqout, 1962). Natural runoff to the playa was augmented with approximately 1.5 × 10^6 L d^{-1} (0.15 ha-m d^{-1}) (range of 1.13 to 1.89 × 10^6 L d^{-1}) of sanitary wastewater generated in the facility (Ramsey et al., 1995) since production began at Pantex in 1942. These wastewaters flow to a sewage lagoon for settling and biological decomposition before being continuously discharged via an open ditch into the playa. Vegetational composition of this playa wetland is altered from those playas not receiving supplemental water with the growth of cattail. Only those infrequent playas modified to be used as tail water pits or in areas that receive highway or feedlot runoffs have cattails. The cattails in this playa were 2 to 3 m tall, 1 to 2 cm in diameter, and required strenuous effort to penetrate. Vegetation of this wetland was divided into two communities with the center of the basin, which was usually flooded, dominated by cattail, whereas the perimeter was occupied by pink smartweed. The smartweed region is generally moist, but only seasonally flooded, following large spring or summer precipitation events.

We collected plant, soil, and water samples over two growing seasons between 20 May 1992 and 19 Aug. 1993. Sampling dates corresponded with early growth of the hydrophytic plants (20 May 1992, 18 May 1993), a midgrowth stage (1 July 1992, 1 July 1993), a late growth stage (18 Aug. 1992, 19 Aug. 1993), and a nongrowing or senescent stage (22 Nov. 1992) that represented a transition between the two growing seasons. A minimum of eight plant and soil samples from each of the two predominant vegetation types were collected each sampling date. We harvested living and dead aboveground biomass from 0.5 by 0.5 m quadrats. Soil samples were collected with a soil probe (i.d. = 2.2 cm) to a depth of 60 cm. Cores, 0 to 30 cm and 30 to 60 cm, were extruded and placed in 475-mL acid-washed glass jars, purged with N_2 gas, capped with plastic screw-on covers, and refrigerated pending chemical analyses. We determined total concentrations of N and P on Kjeldahl digests of the dried material. Total N concentrations were quantified on a Technicon TRAACS 800 Autoanalyzer (USEPA, 1983). We determined total P using an EDTA extraction and a Brinkmann PC 800 Colorimeter (with no. 620 filter) according to Hons et al. (1990). Copper and Fe were DTPA extracted and determined with a Perkin-Elmer Plasma 40 Emission Spectrometer (Lindsay and Norvell, 1978).

We collected samples of surface water concurrently with the plant and soil samples. A tape measure was used to measure the water depth. We transferred water samples, when present, to 1-L, triple-rinsed, acid-washed, polyethylene bottles. All samples were placed in an ice chest and refrigerated until analyzed for total N and total P (USEPA, 1983).

We analyzed the data using a completely randomized design. Water depths, which were considered temporally variable, were considered pairs (cattail and smartweed) and evaluated using paired *t*-tests within each sampling event. Soil, vegetation and water chemistry were analyzed using analysis of variance. Although the design was balanced, there were missing samples due to field and/or laboratory handling errors. We performed statistical analysis using SAS programs (SAS Inst., 1990).

RESULTS AND DISCUSSION

Throughout this study, the cattail portion of the wetland generally had deeper ponded water than did the surrounding pink smartweed area (Table 1), with significant differences ($P < 0.05$) except at the May and July 1993 sampling dates. Differences in the vegetation areas were characterized by water depth, not redox potential. Water depths were dependent upon rainfall events that produced runoff and Pantex facility activity that produced effluent. Water depth varied daily and depth changes were observed several times during sample collection.

Seasonal water quality did not change significantly

Table 2. Comparisons of mean soil nutrients between two vegetation types of a playa wetland at the Pantex DOE facility during 1992 and 1993. Each average value is the mean of 32 samples (16 TKN samples) in 1992 and 24 samples in 1993.

		Vegetation type		ANOVA results		
Parameter	Year	Smartweed	Cattail	Year	Type	Y × T
		mg kg^{-1}		*P* values		
TKN	1992	1760	1450	0.603	0.075	0.743
	1993	1640	1420			
Total P	1992	482	387	0.001	0.090	0.262
	1993	332	313			
Cu	1992	1.15	1.25	0.0001	0.781	0.185
	1993	0.69	0.52			
Fe	1992	25	32	0.005	0.084	0.239
	1993	44	78			

($P > 0.05$) within the wetland. Total Kjeldahl N values ranged 3.75 to 6.85 mg L^{-1} at the inlet of the wastewater treatment stream with the playa water (Fig. 1). These playa values were greater than those reported by the Pantex Environmental Protection Department (1993, unpublished report) for the wastewater treatment facility. Salinity and Na values were not reported in the Pantex report and were not collected in our experiments. Water TKN values in cattail (range 4.06–21.3 mg L^{-1}) were not significantly greater ($P > 0.05$) in concentration than that in water in the smartweed portions (range 1.86–15.7 mg L^{-1}) of the playa (Fig. 1). There was no significant ($P > 0.05$) date × location interaction. Water in the smartweed area was the direct result of runoff whereas the cattail water was deeper and buffered by the smartweed areas. Total P values at the inlet (Fig. 2) ranged from 1.21 to 2.19 mg L^{-1} compared with 1.5 to 2.91 mg L^{-1} for the smartweed areas and 1.2 to 3.15 mg L^{-1} for the cattail areas. There were no significant ($P > 0.05$) date × location interactions, date effects, or location effects.

Water quality within this wetland should be related to season of the year. As suggested by Kadlec (1987), TKN and TP values of surface waters were thought to be highest with the release of nutrients following senescence. Cattail TKN and TP values for November and May, however, were lower than anticipated. Evapotranspiration probably increased the concentrations, whereas runoff and wastewater additions decreased the concentrations. Turbulence and mixing of nutrients typically associated with playas (Sublette and Sublette, 1967) was probably less important in this cattail-vegetated playa. Water currents arising from the wastewater treatment outflow may have distributed the nutrients and subsequently altered the water-quality pattern. Considering the very dense stand of well-established cattails, however, wave action should not have been a contributory factor in the redistribution.

Additions of N, P, Cu, and Fe would be expected annually from the wastewater and runoff to the playa wetland. Wastewater could contribute approximately 5 kg Cu yr^{-1} (wastewater conc. of 0.01 mg Cu L^{-1} × 1.5×10^6 L d^{-1} × 365 d yr^{-1}) and approximately 180 kg Fe per year (wastewater conc. of 0.32 mg Fe L^{-1} × 1.5×10^6 L d^{-1} × 365 d yr^{-1}). The added N from the applied wastewater could be approximately 1100 kg yr^{-1} (2.1 mg N L^{-1} conc. in wastewater × 1.5×10^6 L d^{-1} × 365 d yr^{-1}). Sweeten (1991) reported yearly runoff losses of 0 to 1.12 kg N ha^{-1} from rangeland and 1.1 to 11.2 kg N ha^{-1} from cropland in the Southern High Plains. Because the land surrounding the Pantex playa is a mixture of cropland and rangeland and is approximately 1000 ha in area, natural runoff could contribute approximately 5000 kg N yr^{-1} (1000 ha × 5 kg N ha^{-1} yr^{-1}). If

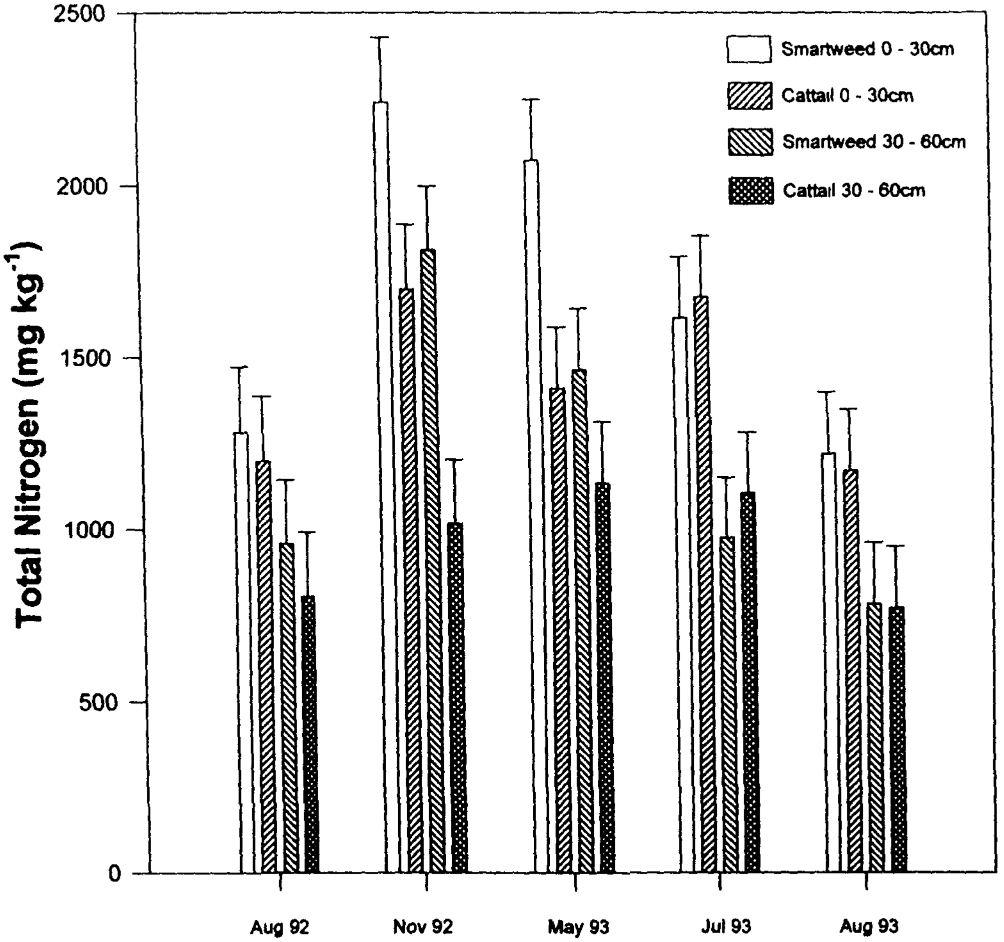

Fig. 3. Soil total Kjeldahl N (+1 SEM) under smartweed and cattail vegetations by depth at the Pantex DOE playa wetland during 1992 and 1993.

the Pantex playa were surrounded entirely by cropland, as are many High Plains playa wetlands, more than twice the N could be added to the wetland. Sweeten (1991) reported annual P runoff losses of 0 to 4.5 kg ha^{-1} for cropland and 0 to 0.3 kg P ha^{-1} for rangeland. Natural runoff could contribute 2000 kg P yr^{-1} (1000 ha × 2 kg P ha^{-1} yr^{-1}) to the Pantex playa. These natural additions of N and P could exceed that contributed from wastewater. For this 37-ha wetland, the annual addition from runoff and wastewater could be 154 kg N ha^{-1} yr^{-1} and 54 kg P ha^{-1}. Copper and Fe additions from the wastewater could be 0.135 kg Cu ha^{-1} yr^{-1} and 4.86 kg Fe ha^{-1} yr^{-1}.

Measured soil concentrations of TKN, TP, Cu, and Fe for the top 30 cm are presented by vegetation type and year in Table 2. There were no significant ($P > 0.05$) year × vegetation type interactions and no significant vegetation type effects. For each soil nutrient other than TKN there was a significant year effect. Due to errors in storage, the TKN samples for May and July 1992 were discarded. Lack of samples due to storage errors could result in lack of year effect on TKN. Concentrations for TP and Cu were higher in 1992 compared with 1993. Iron concentration was significantly higher in 1993 compared with 1992.

Soil TKN values as a function of vegetative type, depth, and date are presented in Fig. 3. Soil TKN values for this playa were similar to those for eight playas that receive irrigation water, but not wastewater as reported by Haukos and Smith (1996). The Pantex data were more cyclic than that reported by Haukos and Smith (1996). The three-way interaction of vegetative type, depth, and date as well as the vegetative type × depth and the depth × date interactions were nonsignificant ($P > 0.05$). There was a significant ($P < 0.05$) vegetative type × date interaction as well as vegetative type, depth, and date main effects. Total Kjeldahl N means were higher in the soil of smartweed areas compared with cattail areas (1400 vs. 1200), and were higher at shallower depths (1600 vs. 1100). Soil TP values as a function of vegetative type, depth, and date in Fig. 4 are approximately 10 times greater than those reported by Haukos and Smith (1996). This difference could be due to our measure of TP vs. their determination of extractable P.

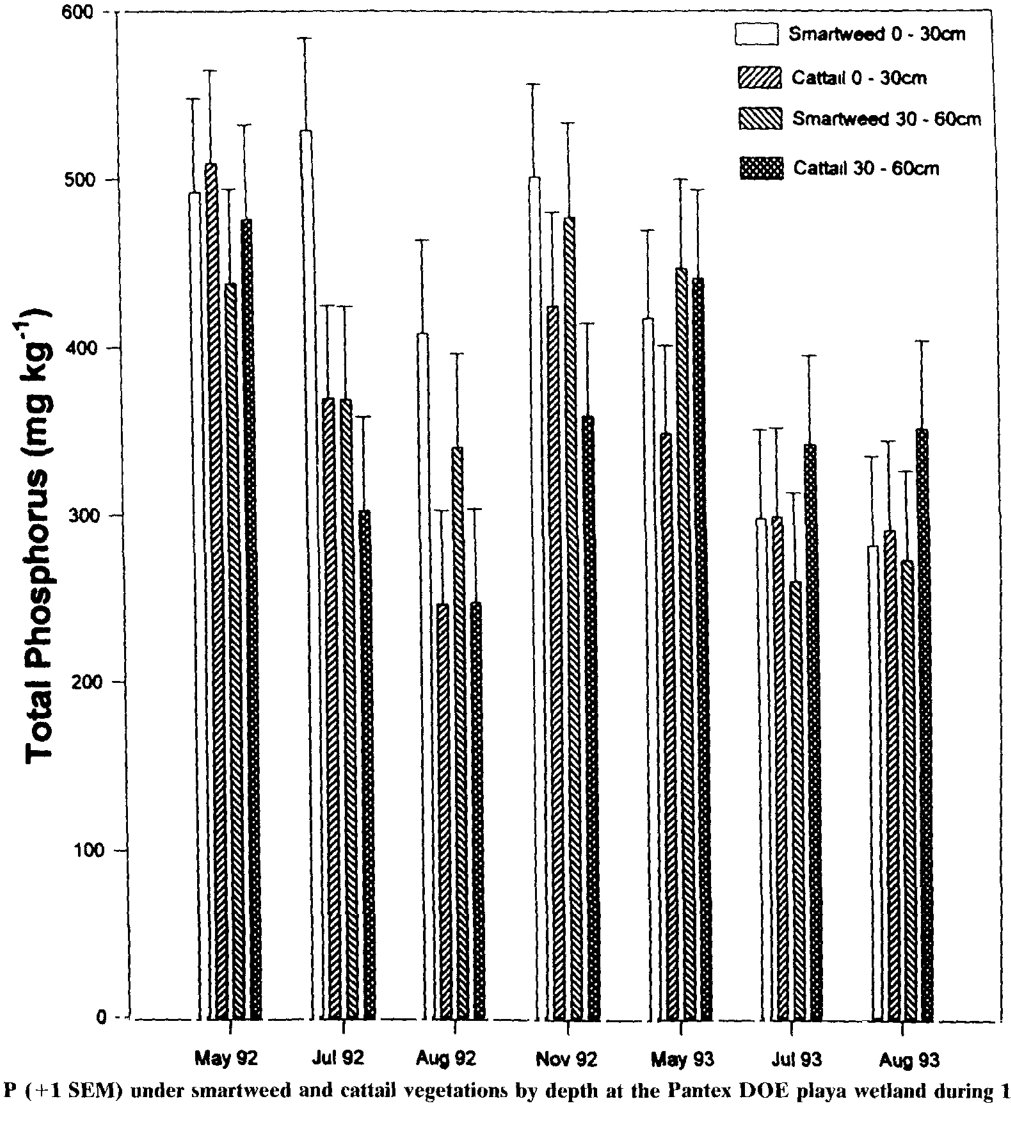

Fig. 4. Soil total P (+1 SEM) under smartweed and cattail vegetations by depth at the Pantex DOE playa wetland during 1992 and 1993.

Table 3. Playa wetland nutrient concentrations and significant differences for two soil depths at the Pantex DOE facility during 1992 and 1993. Each value is the mean of 32 samples (16 TKN) in 1992 and 24 samples in 1993.

		Soil depth, cm		ANOVA results		
Parameter	Year	0–30	30–60	Year	Depth	Y × D
		mg kg^{-1}		*P* values		
TKN	1992	1600	1150	0.583	0.013	0.918
	1993	1530	1030			
Total P	1992	434	376	0.036	0.637	0.164
	1993	322	352			
Cu	1992	1.2	0.76	0.001	0.018	0.195
	1993	0.61	0.48			
Fe	1992	28	23	0.220	0.169	0.296
	1993	61	26			

Table 4. Comparisons of average total nutrients in aboveground biomass between two vegetation types of a playa wetland at the Pantex DOE facility during 1992 and 1993. Each average value is the mean of 32 samples in 1992 and 24 samples in 1993.

		Vegetation type		ANOVA results		
Parameter	Year	Smartweed	Cattail	Year	Type	Y × T
		mg m^{-2}		*P* values		
TKN	1992	3000	9000	0.560	0.038	0.763
	1993	2800	7400			
TP	1992	790	2000	0.246	0.002	0.677
	1993	710	1600			
Cu	1992	10	24	0.117	0.034	0.208
	1993	8.8	20			
Fe	1992	270	370	0.823	0.018	0.052
	1993	250	300			

In both studies, the TP data were similarly cyclical in nature with minimum P values in the late simmer and early fall. There were no significant ($P > 0.05$) three-way or two-way interactions for the soil TP data. The only significant ($P < 0.05$) main effect was for date.

Soil nutrient concentrations for both years for TKN, TP, Cu, and Fe at two depths, 0 to 30 cm and 30 to 60 cm, are presented in Table 3. There were no significant ($P > 0.05$) year × depth interactions for any nutrients. Significantly greater ($P < 0.05$) TKN values occurred at the 0- to 30-cm depth, but there was no year effect on TKN. There was a significant year effect on TP values with higher levels in 1992. There was no significant difference between depths for TP concentrations. Both year and depth differences were significant for Cu with concentrations being higher in 1992 compared with 1993 and higher in the 0- to 30-cm depth compared with the 30- to 60-cm depth. Concentration levels of Fe were not significantly different between years and depths. These results are partially explained by typically higher exchange rates in surface soils compared with soils at depth. Also, shallower depths have more organic material compared with deeper depths, which do not receive the same quantities of plant litter.

Plant biomass followed a seasonal growth trend and increased as a function of time during the growing sea-

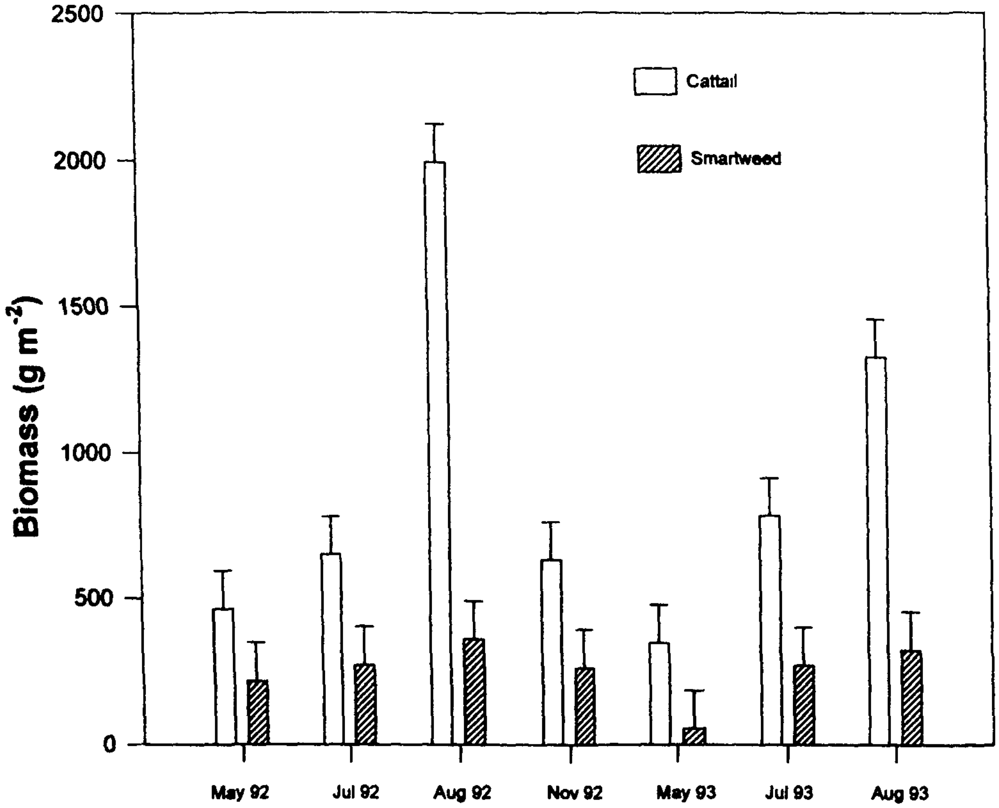

Fig. 5. Aboveground biomass (+1 SEM) as a function of vegetation type and time at the Pantex DOE playa wetland during 1992 and 1993.

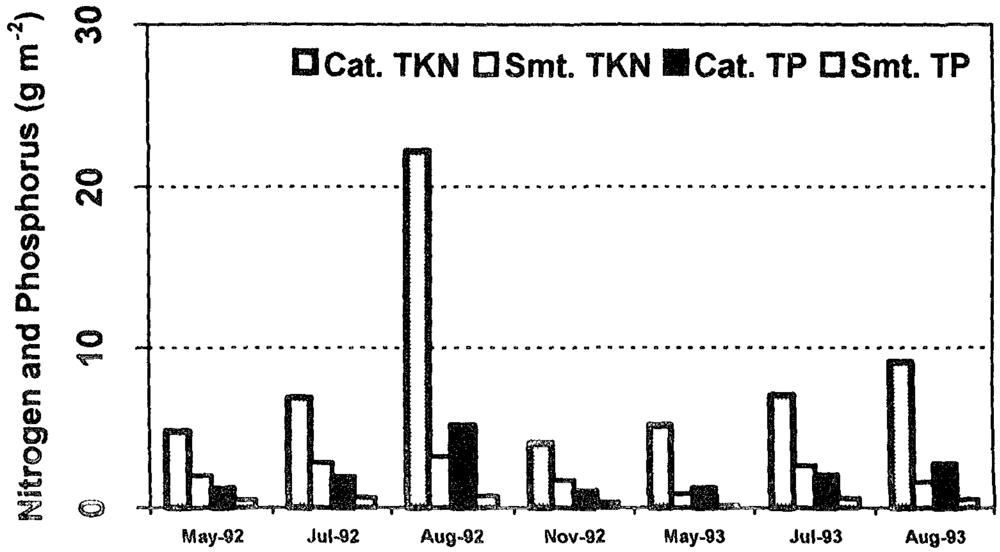

Fig. 6. Total Kjeldahl N and total P for smartweed and cattail at the Pantex DOE playa wetland during 1992 and 1993.

son (Fig. 5). There were significant ($P < 0.05$) interactions between vegetative type and date, as well as main vegetative type and main date effects. Low values for smartweed biomass in early 1993 reflected a dry winter and spring. Smartweed plots harvested in November 1992 were easily identified due to lack of growth early the following year. Cattail biomass averaged 934 g m^{-2} in 1992 and 820 g m^{-2} in 1993. Smartweed biomass averaged 279 and 219 g m^{-2} for 1992 and 1993, respectively. Smartweed biomass values were not significantly different between dates ($P > 0.05$) Cattail biomass in August of both years was significantly different from all other dates ($P < 0.05$). Within specific dates, cattail biomass was significantly ($P < 0.05$) higher than smartweed biomass except in May, at the onset of the growing season.

The average total nutrients in aboveground biomass on an area basis by vegetative type are presented by year in Table 4. There were no significant year × vegetative type interactions and there were no significant year differences. The concentrations of TKN, TP, Cu, and Fe were all significantly higher in cattail biomass compared with the smartweed type. The TKN and TP contents by area are presented as a function of time in Fig 6. The maximum TKN and TP contents generally occurred in August of each year when the biomass was the greatest. November and May values were the lowest representing the loss of nutrients from the plants due to senescence (November) and low biomass (May).

Besides differences in biomass production, there were differences in nutrient concentrations on a mass basis (Table 5) There were no significant month × vegetative type interactions. There were no significant differences ($P > 0.05$) in TKN concentrations between vegetative types. The cattail type, however, had significantly greater ($P < 0.05$) concentrations of TP, Cu, and Fe compared with smartweed. While year effects were earlier shown to be nonsignificant ($P > 0.05$) for TKN, TP, Cu, and Fe (Table 4), there were significant ($P < 0.05$) differences due to months for TKN, TP, and Cu. In general, concentrations were highest in May and declined in later months

Processes that affect the chemical dynamics of a wetland are most closely linked to the import and export of elements through water (Kadlec, 1987). Because playa wetlands are closed drainage basins, the impacts of internal physical and chemical processes and the atmosphere are appreciable. Relationships between surface water and vegetation and/or soil components of the playa were not observed to dramatically alter the playa wetland soil or aboveground biomass. In part, this observation could be because cattail does not exchange elements directly with water during senescence; they may not have been added to the litter or incorporated into the soil for several months or longer. Therefore, exchanges from the vegetation to the water or soil may not have been readily distinguished. Based on these findings, the

Table 5. Comparisons of average nutrient concentration in aboveground biomass between two vegetation types of a playa wetland at the Pantex DOE facility during 1992 and 1993. Each average value is the mean of 16 samples for all months except November, which has 8.

		Vegetation type		ANOVA results		
Parameter	Month	Smartweed	Cattail	Month	Type	M × T
		$kg\ kg^{-1}$		*P* values		
TKN	May	0.012 1	0.012 5	0.000 1	0.401	0.633
	July	0.009 97	0.009 75			
	Aug.	0.006 95	0.009 03			
	Nov.	0.006 58	0.006 39			
TP	May	0.002 39	0.002 99	0.000 1	0.000 4	0.988
	July	0.002 22	0.002 74			
	Aug.	0.001 79	0.002 32			
	Nov.	0.001 24	0.001 66			
		$mg\ kg^{-1}$				
Cu	May	30.8	36.3	0.000 1	0.020	0.399
	July	30.0	30.0			
	Aug.	14.6	24.5			
	Nov.	30.0	35.0			
Fe	May	264	930	0.361	0.019 7	0.731
	June	570	1180			
	Aug.	329	523			
	Nov.	538	760			

Pantex wetland seems to function well as a sink for the added nutrients from the wastewater treatment facility and natural surface runoff.

CONCLUSIONS

We could not perform a complete nutrient mass balance for this playa wetland. We had no direct measurement of the contribution from runoff or any measures of throughput below the playa. We were able to partition the nutrients within the smartweed and cattail portions of this wetland. More detailed information on the quantity and nutrient quality of the organic matter component would also be necessary for a complete nutrient mass balance.

Water TKN and TP status at the inlet of the wastewater stream and the playa water were consistent throughout time. Wetland vegetation TKN, P, and Cu were highest in May when the water levels were low. Cattail and smartweed nutrient concentration levels of TKN, TP, and Cu decreased during the growing season. Total aboveground biomass of cattail was significantly greater than smartweed except in May ($P < 0.05$) for both years. Although not quantified, status of organic material, both as detritus above the soil and within the soil were likely to have contributed to these results.

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