MASS BALANCE ASSESSMENT OF PESTICIDES AND NUTRIENTS APPLIED TO GOLF TURF

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Abstract

There is much concern in the general public, government regulators and environmentalists as to the impact of fertilizers and pesticides applied to golf courses on water quality. The early studies in this area suggests that fertilizers and pesticides applied to turf had little or no impact on groundwater quality. However, these studies were of limited scope (few or one soil, limited number of pesticides and climatic factors). The objective of this project was to develop a better understanding of the factors and conditions that lead to pesticide and fertilizer leaching from golf type turf (fairways and greens). The leaching of five pesticides (MCPP, triadimefon, trichlorfon, isazofos and metalaxyl) and fertilizer elements (NO3-N, NH4-N and PO4-P) were evaluated under well maintained fairway conditions and three soils types (sand, Arkport sandy loam and Hudson silt loam). Normal and extremely wet precipitation conditions were also evaluated.

Under normal precipitation-irrigation conditions, in general, pesticide leaching was very limited to near zero (with except of MCPP applied to young-thin turf) even with highly leachable pesticides. When conditions were considered "worst case" (thin-immature turf, sand soil, heavy rainfall shortly after application or excessively wet, over-irrigated turf), pesticide leaching was substantial. The leaching of phosphorus from fertilization was zero, even from the sand. Nitrate leaching was limited and only influence by soil type (sand 9 %, silt loam 3% and sandy loam 1.5% of the amount applied) not precipitation-irrigation amount. From half (sandy loam) to over 90 % of the applied N in the fertilizer was recovered in the clippings, while only 9 % was recovered in the clipping from the sand lysimeters. Most of the remaining fertilizer N was found in the soil (as either roots, organic matter or fertilizer). The total estimated N recovery was slightly larger than the amount applied. Generally, there was good agreement in the data between the traditional N source and analytical method and the enriched N15 fertilizer and mass spec analysis to recommend the use of the traditional methods because of a lower cost unless detailed soil and atmosphere N fate is needed.

Introduction

The information on the fate of pesticides and fertilizers in the turfgrass environment is limited, but generally supports the notion that pesticides and fertilizers are unlikely to runoff into surface waters or leach into groundwater. The initial studies done under turfgrass conditions were conducted under a limited set of conditions (little or no comparisons of soils or grass species/cultivars, irrigation practices, only a few pesticides studied) leaving room for speculation on the fate of these and many other pesticides applied to sites not well represented in the early studies. Thus, there is an urgent need to develop a broader understanding of the environmental fate of pesticides and fertilizers applied to golf type turfgrass. Therefore, the objective of this project is to develop a better understanding of the factors and conditions important in the leaching of pesticides and fertilizers applied to an experimental golf fairway following establishment. The ARESTS facility was utilized for this purpose where soil types (sand, silt loam and sandy loam) and post application precipitation factors could be studied. An additional objective was to compare two ways of evaluating the fate of N by using a traditional N source and analytical methods compared to a heavy N isotope (N15) N fertilizer source and a ratio mass spectrophotometer for quantification.

This project is part of a larger study of the mass balance of pesticides applied to turf that involves runoff (Penn State Univ.) and volatilization/dislodgeable residues (Univ. of Massachusetts) of the same list of pesticides applied to similar turf and one soil type (silt loam).

Materials and Methods

There were two sites used for the studies. Most of the experiments were conducted in the ARESTS (Automated Rainfall Exclusion System for Turfgrass Studies) Facility and a few studies were run in the mini-greens lysimeter facility. Both facilities are located at the Cornell University Turfgrass Field Research Laboratory, Ithaca NY. The ARESTS Facility contains 27 draining lysimeters (3.2 m X 3.2 m), a rainout shelter (12 m X 36 m), and each lysimeter individually irrigated and drained that were linked to a data acquisition/control system. Each lysimeter contains 37 cm of soil, double plastic lined on all side and bottom with seven 3 cm perforated drain line per lysimeter piped to a common outlet that feeds a tipping bucket for volume determination and to collect a proportional sub-sample for leachate analysis. Nine lysimeters were filled with 3 different soils: sand (Blue Ridge Peat farms sand C), an Arkport fine sandy loam and a Hudson silt loam. One lysimeter of each soil type was only seeded, watered and used as an untreated check for corrections in nutrient recovery calculations. The site was seeded with Penncross creeping bentgrass in May ,1991 at 1 lb/1000 sq.ft. This site was maintained as a fairway: mowing done three times per week during most of the growing season (clippings removed and a sub-sample ovendried and analyzed for N and P) and at least 25 mm of precipitation was applied per week.

The mini-green facility contains 96 greens constructed in a 4.1 m2 plastic container (kiddy swimming pool) fitted with a single floor drain to collect leachate. Each mini-green had 10 cm of pea gravel placed in the bottom, covered with 5 cm of a coarse sand and filled with 30 cm of either sand (Potter Sand and Gravel washed mason sand) or sand with 20 % by volume of reed-sedge peat (Dakota Reed Sedge Peat) added. The site was sodded with washed Penncross creeping bentgrass sod in September of 1992. There were 4 replicated of sand, sand/peat mini-greens and three replications of an Arkport fine sandy loam (filled the entire 45 cm to represent older "pushup" greens).

Pesticides were applied to the two facilities at the rates and timing shown in Table 1. Pesticides applied to the sand lysimeters in 1991 were applied to thin poorly established turf (4 months old). To all other soils and later years in the study, pesticides were applied to dense well established turf (except for the turf density study).

The fertilization program consisted of using a commercially available fertilizer

(Scotts Hi Maintenance Fertilizer 32-3-10, urea/methylene urea as N sources) on 4 of the 8 treated plots per soil type. The other 4 plots received an similar fertilizers (29-3-7 small batch produced by Scotts) that contained 2 % enriched N15. The fertilizer was applied at a rate of 1 lb of N/1000 sq.ft on the following five dates: 12 September, 1991, 8 October, 1991. 3 June, 1992, 22 September, 1992 and 28 October ,1992. Fertilizers were to be applied in 1993 (May treatment was made), however, a major lighting storm totally destroyed the data acquisition/control system which disrupted the continuity necessary in a study of this nature. Therefore, only data through 1992 will be concluded. Using a heavy isotope of N allowed us to track fertilizer N in the plant and leachate. All leachate, plant and soil samples were analyzed with traditional wet chemistry methods by the Cornell Nutrient Analysis Laboratory , Ithaca, NY. In addition, samples of soil, clipping and leachate plots treated with the N15 enriched fertilizer were analyzed for N15-N by a ratio mass-spectrophotometer in the laboratory of Dr. John Duxbury, Dept. of Soils, Crops and Atmosphere Sciences, Cornell University, Ithaca, NY. Every leachate sample was analyzed for NO3-N, NH4-N and PO4-P. Clipping samples were combined to give monthly samples and analyzed for total N and P. Soil samples were taken before the study started (3 September 1991) and again on 4 November and 1992, and the difference is report. Three 5 cm dia. samples per plot were taken and bulk density determined and used to convert concentration into amount of total N or P. A bulk density of 1.50 g/cm3 was assumed in the calculations since it was difficult to obtain a truly undisturbed sample, especially with limited turf root density in the first sampling.

There are attached 6 referred publications covering the pesticide leaching studies from this project. Please refer to them for a more detail description of the experimental protocol and analytical procedures used.

Results and Discussion

Nitrogen and Phosphorus Fate

Figures 1-3 contain the precipitation amounts (which included natural rainfall, snow melt and irrigation) and the volume of leachate that resulted from the precipitation. There was little difference between soil types in the amount of leachate volume. The sand soil was slightly higher in some cases. There is a general belief that the is a higher percentage of the amount of precipitation that produces leachate in sandier soils.

Figures 4-9 contain the average concentration of NO3-N, NH4-N and PO4-P in the leachate as influenced by soil type and precipitation amount. The concentration of PO4-P in the leachate ranged from zero to a high of 0.62 mg/L, where most of the values were about 0.1 mg/L and only 2 values exceeded 0.2 mg/L. In fact, the concentration of PO4-P in the unfertilized lysimeters of each soil type were greater than the fertilized lysimeters, indicating the P is unlikely to leach into groundwater when applied to a creeping bentgrass fairway. The concentration of NO3-N in leachate never exceeded 5 mg/L in the Arkport sand loam and Hudson silt loam lysimeters. Only four times out of the 50 leaching events was the concentration greater than 10 mg/L (the HAL for drinking water) from the sand lysimeters. In each case the high NO3-N levels occurred for a short time after the October fertilizer application.

Tables 2 and 3 contain the total amount of N and P recovered in the leachate, soil and clippings during the study. Tables 3 and 4 contain the amounts recovered on a per cent of the amount applied bases. Only the soil types were significantly different ($P=0.05$), so the data was pooled to only show the soil type main effect. The highest amount of N and P recovered in the clippings was from the Hudson silt loam soil, 91 and 65 % of the amount applied, respectively. About half the amount of N and P were recovered in the clipping in the Arkport sandy loam soil plots. However, only about 8 % of the N and P fertilizer applied was recovered in the clippings from the sand plots. Others have found a much greater recovery of N in the clipping of creeping bentgrass sand greens. Much of the applied N was accumulated in the soil (including root) and possibly in the thatch or lost back to the atmosphere via denitrification or ammonium volatilization.

The amount of N leaching was also only affected by soil type. On a per cent applied bases, sand had the greatest amount of leaching (9.1%) followed by the Hudson silt loam (3.1 %) and the Arkport sandy loam (1.5 %). This is the first cool-season turfgrass study to compare NO3-N leaching as a function of soil type. Our results compare to what was found in warm-season greens studies that sand has about 6 times more NO3 leaching than a sandy loam soil.

Table 6 contains the summary results from the N15 recovery in clippings and leachate. Comparing the results of the N15 method and the traditional method in determining the fate of N in a turfgrass system shows remarkably similar findings. There was a slightly higher N15 leaching from the sand, a slightly lower recovery on N15 in the clippings compared to the traditional method and more N15 accounted for in soils than using the traditional method. When using the traditional method an untreated control plot must be used and all irrigation water must be analyzed for nutrients which is likely to be cheaper than the N15 (for this study the N15-urea cost $ 22,000).

Pesticide Leaching

Parts of this study would be considered as "worst cases scenario" type studies. These include: using sand that is very low in organic matter, using pesticides that are moderately to highly leachable, having a thin (or no turf) turf on sand, and excessive irrigation/precipitation. Unfortunately, all these situation can happen on a real golf course. Metalaxyl is used as a seed treatment where creeping bentgrass seed is applied to a bare sand or a sand/peat mixture. Golf courses have high sand based area like greens/tees and some fairways are naturally very sandy. Over-irrigation is not common but with poorly designed and operated systems it is certainly a possibility. Having a heavy rainfall within several days after application also is a real possibility. However, some sections of this study are more typical of golf course conditions: native soils found on fairways, normal precipitation and no more that one inch of irrigation per week, and high density turf. With this in mind the following are summaries of the leaching of pesticides applied to experimental fairways and greens.

Insecticides: trichlorfon and isazofos

Table 7 contains a summary of the leaching of trichlorfon and isazofos. Trichlorfon is highly water soluble and has a low potential for binding onto organic matter, but has a very short half life and is considered a highly leachable pesticide. Thus, if a major precipitation or irrigation event that resulted in substantial movement of water through the soil, leaching of trichlorfon would be expected. We observed this to be the case where trichlorfon was applied and within 8 days after application 9.6 " (wet year) and 4.4 " (normal year) precipitation occurred and substantial leaching resulted. In fact soil type had very little effect on the extent of trichlorfon leaching.

Isazofos is also considered to have a high potential for leaching, especially in low organic matter-sandy soils. Our data confirms that isazofos does easily leach through sand (8 % of the applied pesticide that leached) but will not in the more typical fairway soils of a sandy loam (0.06 %) or a silt loam (0.46 %) soil.

Metalaxyl

Fungicides are generally considered to have a low potential for leaching due to their low water solubility and their high organic matter binding. Two fungicides, however, have a high potential for leaching, fenarimol and metalaxyl. We studied the leaching of metalaxyl as influence by peat amendment of sand and turf density under very high precipitation-irrigation conditions (average of 3.1 cm/day for the 66 days of the study). As expected in this worst case scenario, there was extensive metalaxyl leaching (Table 8). Unexpectedly, more leaching occurred from greens that had their root zone modified with peat at construction than just sand. The leaching pattern revealed that the metalaxyl must have been bound to the organic matter (peat and turf-thatch) and was not degraded but leached at a later time. There was a good agreement between the amount of surface organic matter (turf and thatch) and a reduction in metalaxyl leaching. Having at least a 66 % turf cover resulted in the lowest metalaxyl leaching, even under these very severe leaching conditions.

Triadimefon and Triadimenol

Triadimefon has an intermediate potential for leaching. As seen in Table 9, there was very limited triadimefon leaching from the sandy loam and silt loam lysimeters and more from sand especially at the high precipitation rate (2.44 % of applied triadimefon leached). On one lysimeter of each soil type, leachate samples were also analyzed for the primary metabolite triadmenol. The concentrations of triadimenol in the leachate samples were much greater than the parent material in most samples. In this case, as is with some other pesticides like DCPA and fenamiphos, the metabolite is much more mobile and more likely to leach than the parent compound.

Mecoprop (MCPP)

Most broad-leaf herbicides have a moderate to high potential for leaching including MCPP. There were three studies involving MCPP: one where MCPP was applied to very young and thin turf (1991), the second where MCPP was re-applied three years (1994) later to the same plots and MCPP applied to mini-greens that had sand or sand amendment with peat (20 % by volume). Applying MCPP to either the sandy loam or soil loam lysimeters resulted in only a limited amount of leaching (<1.7 % of the amount applied) or no leaching even to young but dense turf (Table 10). In contrast, there was substantial leaching of MCPP (51-62 % of the amount applied) from the sand lysimeters that were 4 months old and thin. However, when re-applied three years later to the well established-dense sand lysimeters, MCPP leaching was considerably less (7.7 % of the amount applied at high leaching conditions) and to a level near the other soils under normal precipitation conditions.

Conclusions

We observed that soils, precipitation, turf density-maturity and pesticide properties play a major roll in the extent of pesticide leaching. Sand (with and without peat) and /or thin immature turf that receives a heavy rain-irrigation event soon after application can expect extreme pesticide leaching from highly leachable pesticides. In contrast, a mature dense turf that receives normal rainfall-irrigation (even on sand) can expect little or no pesticide leaching to occur.

In most cases there was more pesticide leaching from the Hudson silt loam lysimeters than from the Arkport sandy loam lysimeters. The Hudson silt loam has a lower leaching potential than the Arkport soil due to a greater organic matter content and lower expected amount of leachate volume. There was considerably more earthworms present in the Hudson silt loam lysimeters than the other two soils. Earthworms have been shown to create channels that allow for macro-pore flow (preferential flow) which increases the extent of pesticide leaching. The pattern in the leachate concentration verse time plots suggest that pesticides are moving preferentially through the Hudson silt loam plots when conditions for preferential flow occur (high rainfall-irrigation rate).

If highly leachable pesticides are to be used then some caution must be exercised to reduce the potential for leaching.

> * Post application of irrigation must be conservative so as not to produce substantial leachate. Other studies of ours suggest that the first 7 days after application is most crucial in pesticide leaching.
>
> * If heavy rainfall is predicted with 48 to 72 hrs., then the use of a low leaching potential pesticide is warranted especially on sandy sites.

The leaching of nitrate and phosphorus from experimental fairways is limited at best. A mid-fall (October) nitrogen application was more likely to result in higher nitrate levels in leachate than when applied in May or September. Nitrate leaching was lowest from the Arkport sandy loam lysimeters (1.5 %), intermediate in the Hudson silt loam (3.1 %) and highest from the sand lysimeters (9.1 %). Precipitation-irrigation had no effect on the extent of leaching or recovery in the clippings. More N and P was recovered in the clippings of the highest organic matter content-finest textured soil (Hudson silt loam) than the other soils. Very little of the N and P applied to the sand lysimeters was recovered in the clippings of this young turfgrass sward. In time, greater recovery in the clippings would be expected following the period of rapid root development and organic matter deposition.

Table 1. Application dates and rates of pesticides used in leaching studies.

Pesticide	Study Years	Application Dates	Application Rate g A.I./m^2	Site
MCPP	1991	24 September	2.10	ARESTS*
(Mecomec 4)	1994	18 August	1.40	ARESTS
Triadimefon	1991	24 September	0.15	ARESTS
(Bayleton 25)		11 October	0.30	ARESTS
	1992	15 September	0.30	ARESTS
		27 October	0.30	ARESTS
Trichlorfon (Proxol 80 sp)	1992	2 July	0.91	ARESTS
Isazofos (Triumph 4e)	1992	2 September	2.28	ARESTS
Metalaxyl (Pace 100-690)	1995	10 August	0.14	Mini-greens (sand, sand/peat)

* ARESTS (Antomated Rainfall Exclusion system for Turfgrass Study maintained as creeping bentgrass fairway turf.

Table 2. Total amount of N accounted for in clippings, soil and leachate; creeping bentgrass fairway turf.

Soil	Total N in clippings	NO_3 -N + NH_4 -N in leachate	Change in total N in Soil	Range of Total N Recovered
	------------------------------ g/plot	------------------------------		
Arkport sandy loam	162 ± 1.6*	4.7 ± 0.2	-43.4 ± 50.2	71.3 - 175.3
Hudson silt loam	217 ± 1.7	9.2 ± 0.4	-71.9 ± 4.9	147.3 - 161.3
Sand	19 ± 0.5	24.3 ± 1.3	261.3 ± 11.7	270.1 - 318.1
LSD (P=0.05)	1	0.5	NS	

* Average of 8 plots ± S.E. for the period of Sept. 1991 - Dec. 1992. Amount of total N applied was 234 g/plot (232 g from fertilizer and 2 g from irrigation water).

Table 3. Total amount of P accounted for in clippings, soil and leachate; creeping bentgrass fairway turf.

Soil	Total P in clippings	Total PO-4 in leachate	Change in total P in soil	Range in total P recovered
Arkport sandy loam	18.6 ± 0.2*	0.22 ± 0.02	9.12 ± 5.23	22.49 - 33.39
Hudson silt loam	24.7 ± 0.2	0.21 ± 0.01	2.34 ± 4.06	22.98 - 31.52
Sand	1.8 ± 0.1	0.63 ± 0.02	-2.78 ± 2.16	-2.63 - 1.93
LSD	0.1	0.05	1.42	

* Average of 8 plots ± S.E. for the period of Sept. 1991 - Dec. 1992.
Amount of P applied was 24 g/plot (as fertilizer only).

Table 4. Total amount of N recovered in clippings, soil and leachate as a per cent of applied nutrient; creeping bentgrass fairway turf.

Soil	Total N in clippings	NO_3 -N + NH_4 -N in leachate	Range in total N in soil	Total N Recovered
		% of applied		
Arkport sandy loam	52*	1.5	< 0	53.5
Hudson silt loam	91	3.1	< 0	94.1
Sand	8	9.1	106.4 - 116.7	124 - 134

* Corrected for the amount recovered in unfertilized plots and amount in irrigation water.

Table 5. Total amount of P recovered in clippings, soil and leachate as a per cent of applied nutrient; creeping bentgrass fairway turf.

Soil	Total P in clippings	Total PO-4 in leachate	Total P in soil	Total P recovered
	-------------------------	% of applied	------------------------------	
Arkport sandy loam	53	0**	5.5	58.5
Hudson silt loam	65	0	< 0	65
Sand	7.5	0	< 0	7.5

** Less than unfertilized plots for each soil.

Table 6. Recovery of N15 enriched fertilizer N in clippings, soil and leachate of creeping bentgrass fairway turf.

Soil	Total N15 in leachate	Total N15 in clippings	Total N15 in Soil	Total N15 in leachate	Total N15 in clippings	Range of total N15 in Soil	Range of total N15 recovered
	-------------- mg / plog ---------------			--------------------- % of applied ---------------------			
Arkport sandy loam	66 ± 9.4*	1,943 ± 245	3,937 ± 485	1.4	41	74 - 95	112 - 144
Hudson silt loam	108 ± 17	3,022 ± 58	3,700 ± 415	2.3	65	71 - 89	144 - 157
Sand	718 ± 53	343 ± 32	3,488 ± 1,218	15.4	7.3	92 - 144	113 - 169
LSD (P=0.05)	270	98	NS				

* Average of 4 plots ± S.E. for the period of Sept. 1991 - Dec. 1992. Total amount of N15 applied plus amount found in the irrigation water was
4,648 mg/plot.

Table 7. Summary results from trichlorfon and isazofos leaching studies.

			Precipitation			
Pesticide	Site	Soil	Type [t]	Total Amount	Maximum Concentration	% of Applied pesticide leached
				mm	µg L $^{-1}$	
Trichlorfon	ARESTS	Sand	Above	385	407	3.44 ± 1.36*
			Normal	231	164	1.18 ± 0.43
		Sand loam	Above	385	302	4.41 ± 1.04
			Normal	231	118	1.13 ± 0.18
		Silt loam	Above	385	504	3.33 ± 0.48
			Normal	231	71	0.63 ± 0.13
Isazofos		Sand		158	504	8.00 ± 1.41**
		Sandy loam		158	6	0.06 ± 0.04
		Silt loam		158	77	0.46 ± 0.22

[t] = Refers to above and normal precipitation for Ithaca, NY

* = Average of 4 replicates ± S.E.

** = Average of 8 replicates ± S.E.

Table 8. Summary of metalaxyl leaching study.

Soil	% Turf density	Total leachate volume L/plot	% of precipatation & irrigation as leachate	% of applied metalaxyl in leachate
Sand	100	6402	57	17.2 ± 2.2*
Sand/peat	100	6751	60	26.8 ± 4.0*
Sand	0	5679	51	36.4 ± 0.4**
Sand	33	5545	49	26.7 ± 3.4**
Sand	66	6136	55	14.1 ± 2.5**
Sand	100	6497	58	16.5 ± 1.4**

* Average of 4 replicates ± S.E.

** Average of 3 replicates ± S.E.

Table 9. Summary results from Triadimefon leaching studies.

				Triademefon		
Site	Year	Soil	Precipitation Year	Maximum Conc.	% of applied leaches	Triadimenol maximum conc.
				$\mu g\ L^{-1}$		$\mu g\ L^{-1}$
ARESTS	1991	Sand	1950	75	1.00	
			1917	72	2.44	616
		Sandy loam	1950	1	0.06	
			1917	1.5	0.01	22
		Silt loam	1950	18	0.24	
			1917	32	0.28	18
	1992	Sand	1950 / 1917	35	---------	115

Table 10. Summary results from MCPP Leaching studies.

Pesticide	Site	Year	Soil	Precipitation Year	Precipitation Total Amount	Total Leachate Volume	% of precipitation that was leachate	Maximum Conc. in leachate	% of applied pesticide leached
					---------- mm	---------		µg L $^{-1}$	
MCPP	ARESTS	1991	Sand	1950	220	148	67	1250	51.0
				1917	270	185	69	825	62.1
			Sandy loam	1950	370			51	1.69
				1917	459			8	0.10
			Silt loam	1950	370			60	1.01
				1917	459			46	1.26
		1994	Sand	1950	128	124	97	140	7.7
				1917	60	30	50	105	0.9
			Sandy loam	1950	191			BD*	<< 1
				1917	101			1.4	<< 1
			Silt loam	1950	191			BD	<< 1
				1917	101			4.5	<< 1
	Mini-greens	1992	Sand					8	<< 1
			Sand peat					BD	<< 1

* Below detach limit of 1.0 mg L $^{-1}$

Figure 1. Precipitation and leachate volumes for the sand lysimeters. Rain wet (1917) and dry (1950) refer to precipitation values and sand wet and dry refer to leachate values.

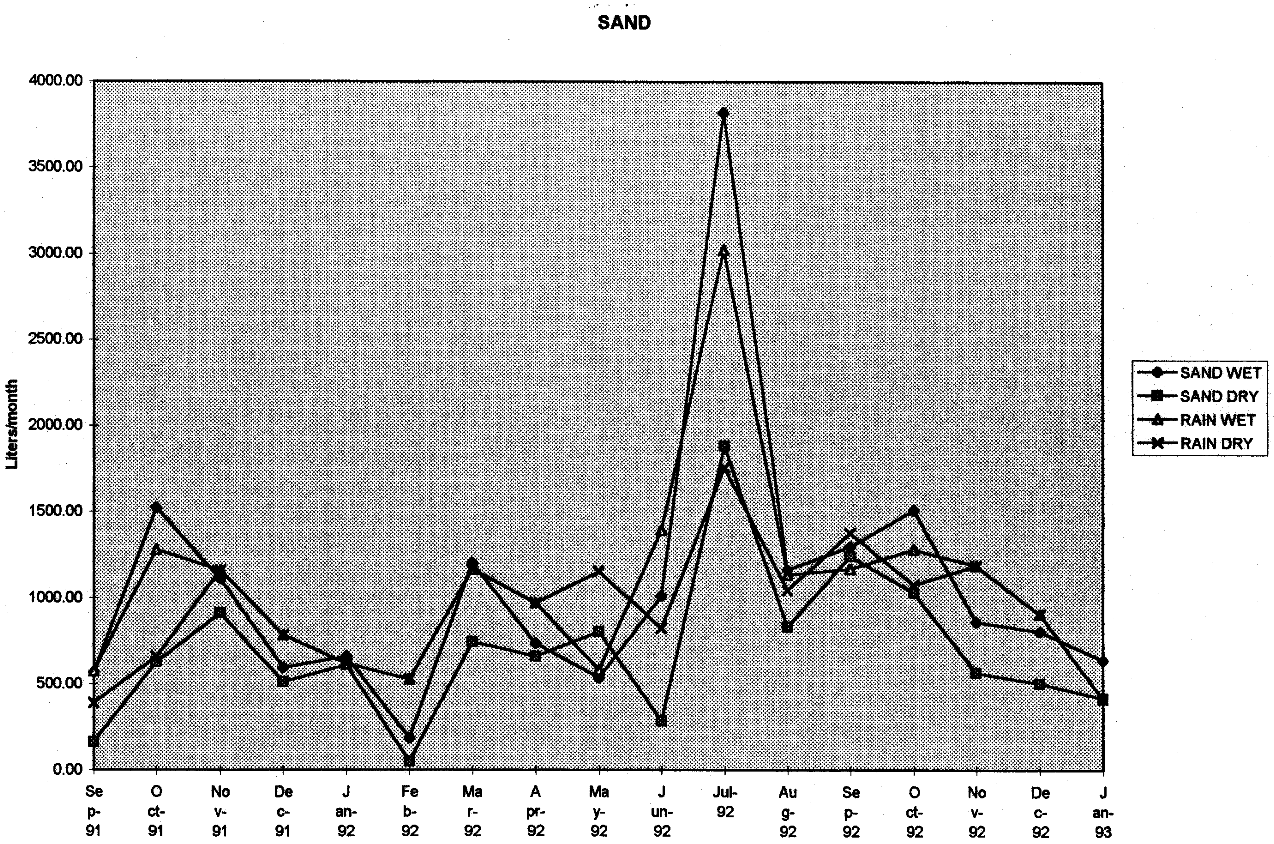


Figure 2. Precipitation and leachate volumes for the Arkport sandy loam lysimeters. Rain wet (1917) and dry (1950) refer to precipitation values and Arkport wet and dry refer to leachate values.

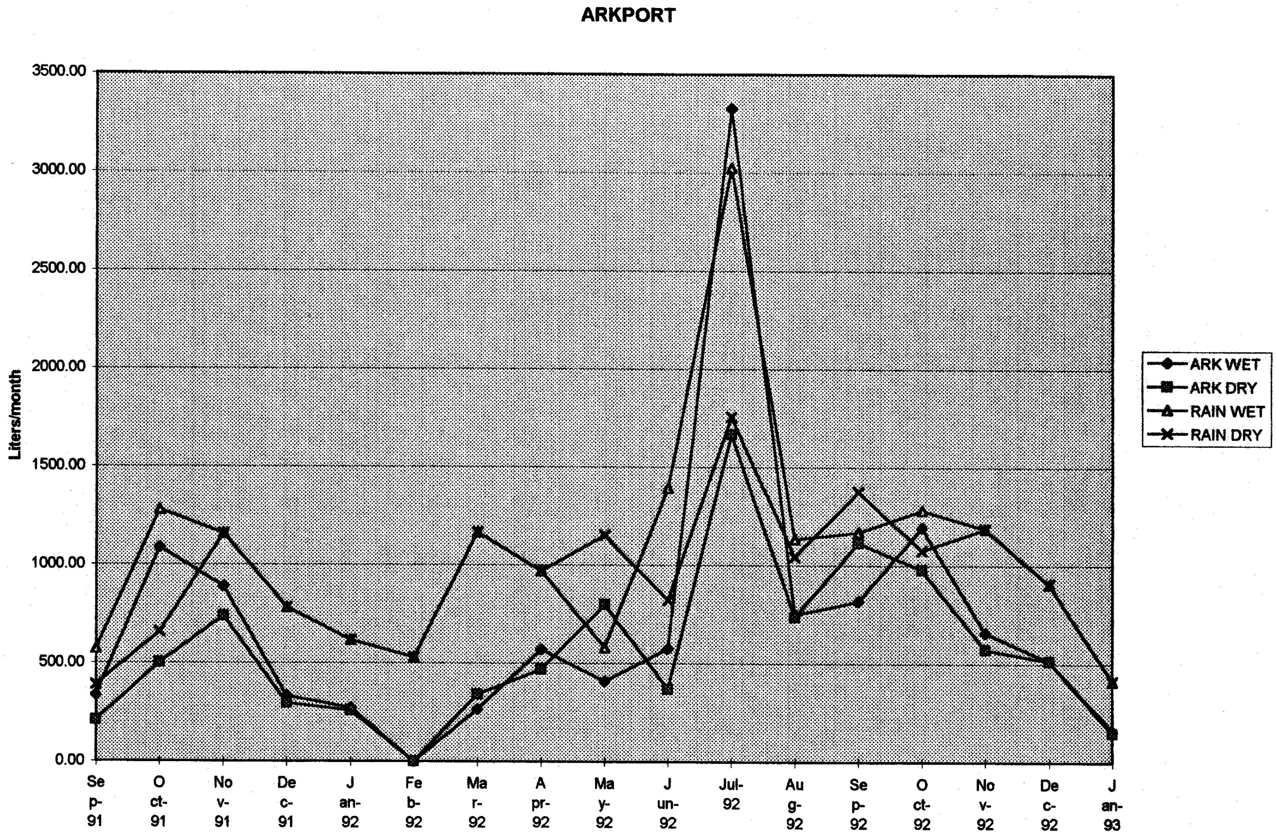


Figure 3. Precipitation and leachate volumes for the Hudson silt loam lysimeters. Rain wet (1917) and dry (1950) refer to precipitation values and Hudson wet and dry refer to leachate volumes.

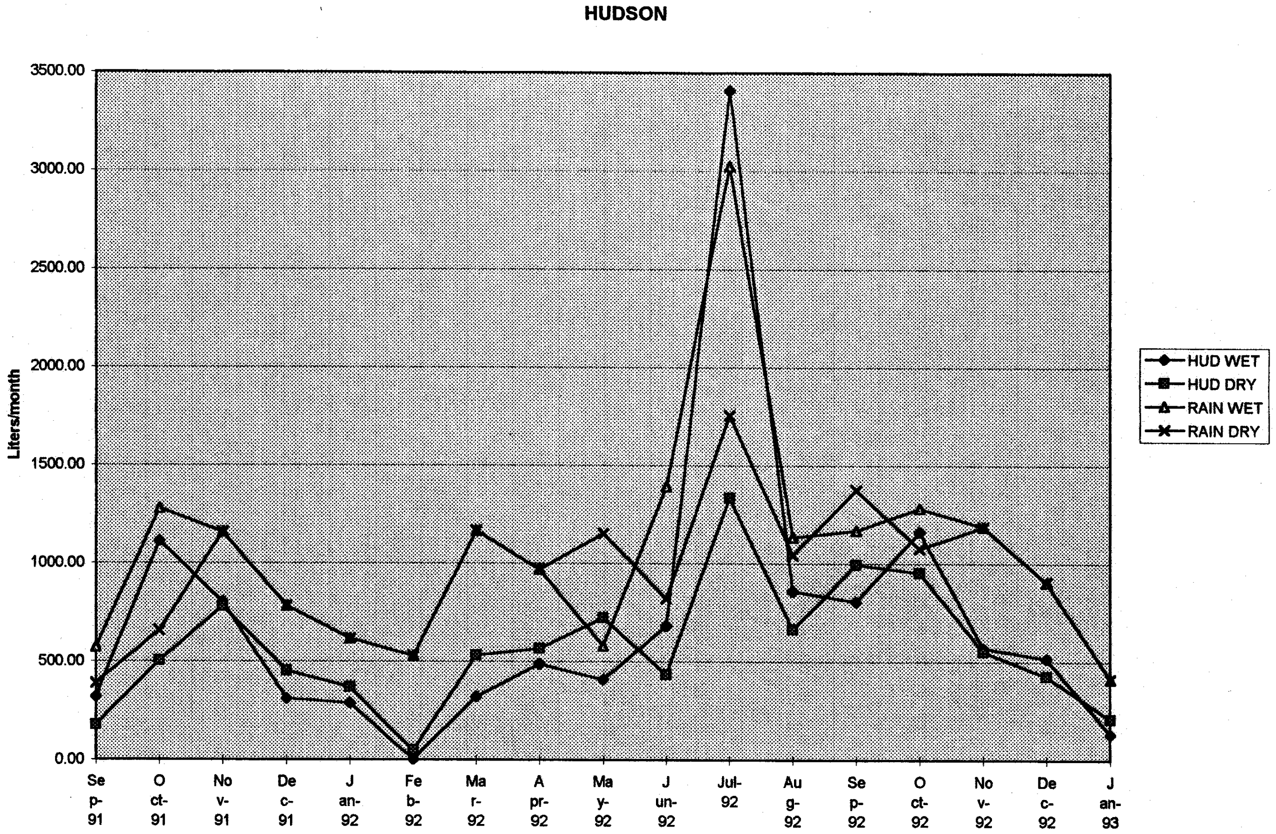


Figure 4. Average nitrate-N concentration in leachate during the dry year, 1950, for each soil.

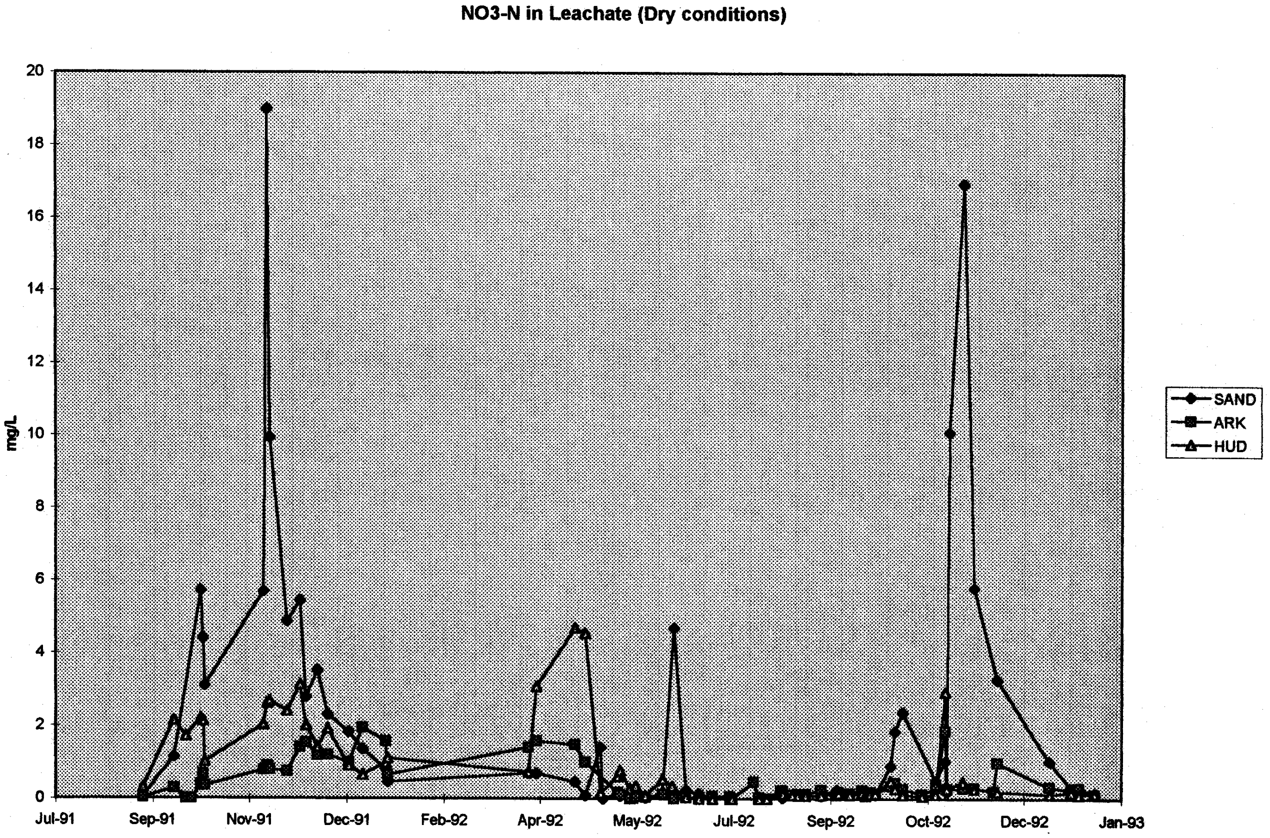


Figure 5. Average nitrate-N concentration in leachate during the wet year, 1917, for each soil.

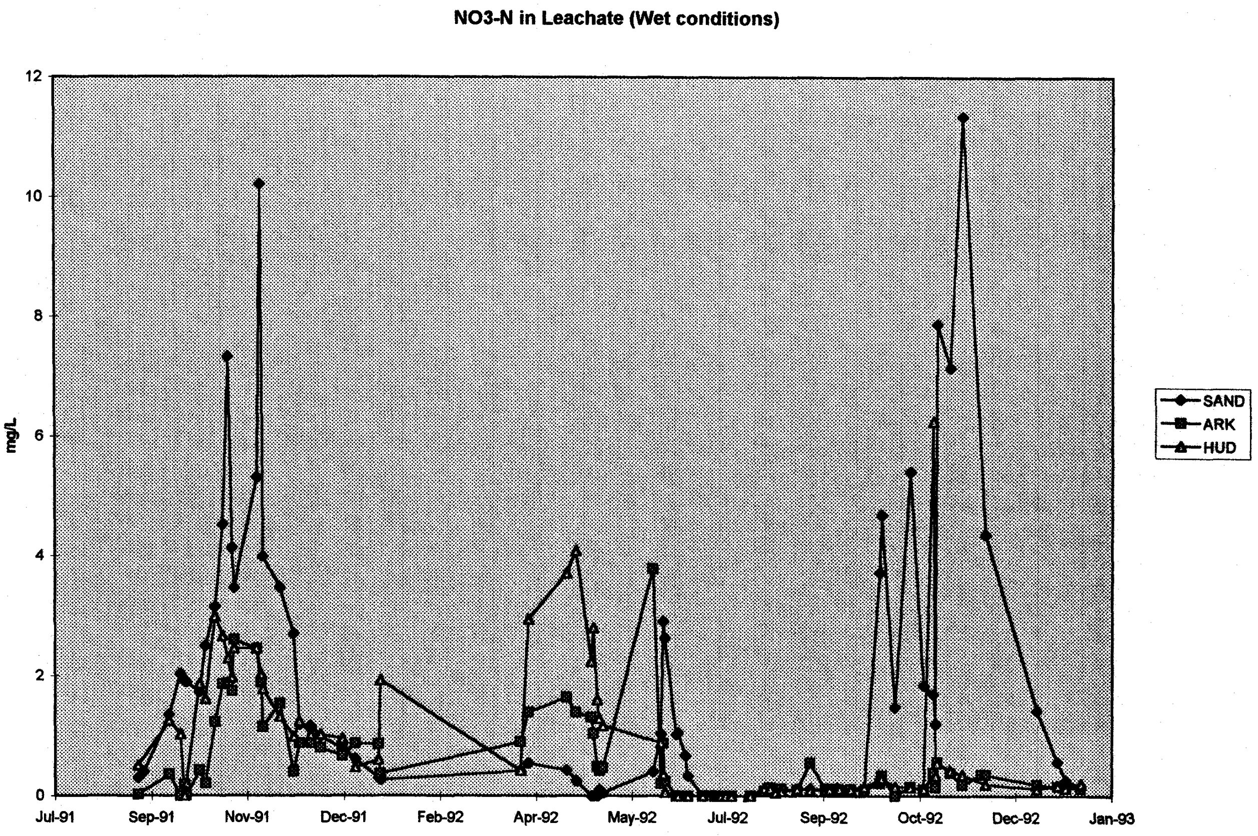
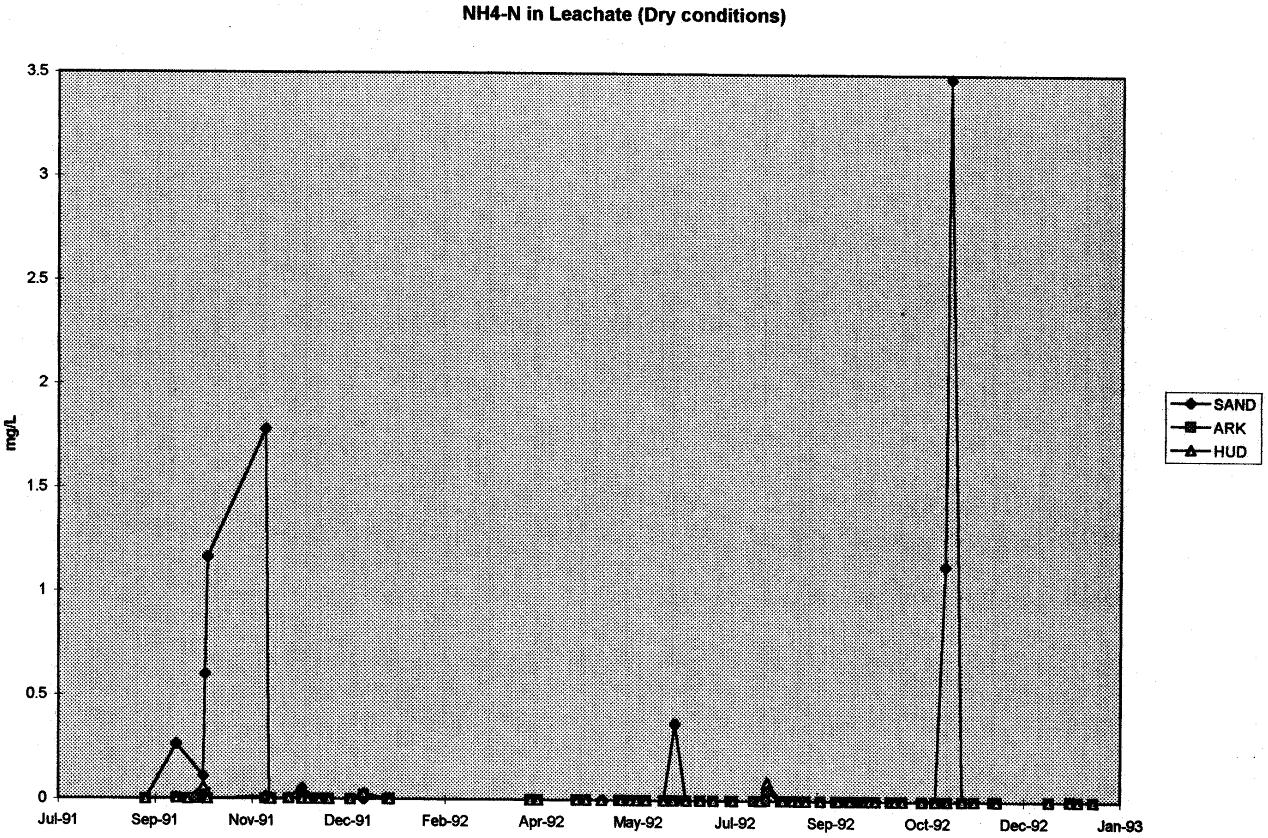


Figure 6. Average ammonium-N concentration in leachate during the dry year, 1950, for each soil.



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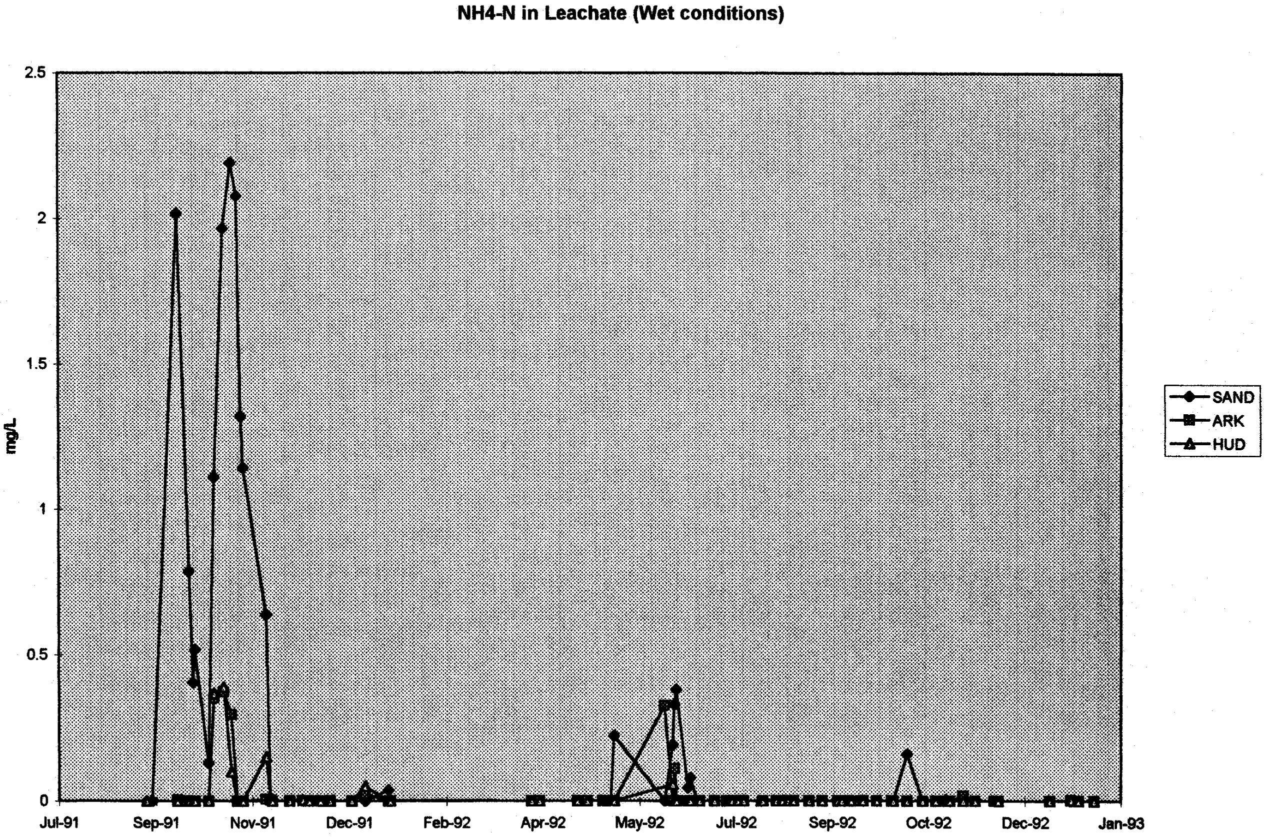
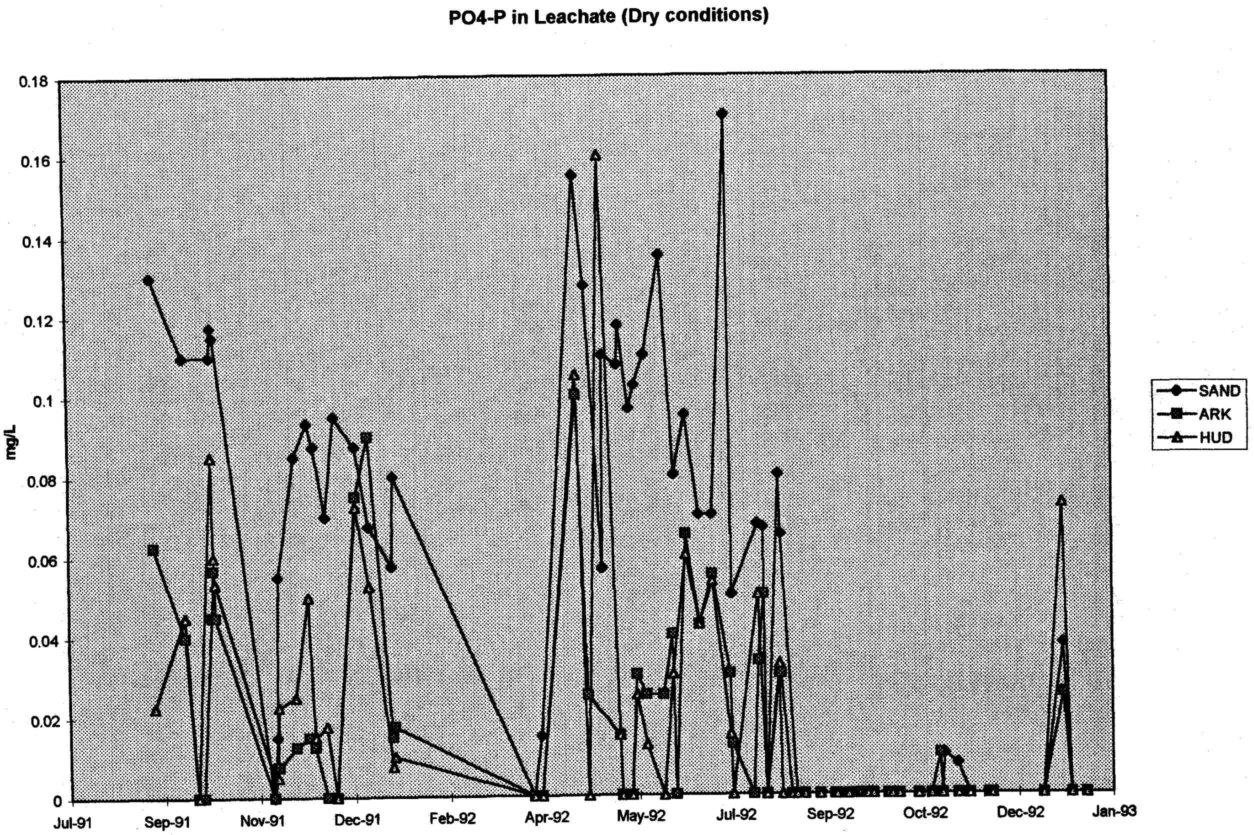


Figure 8. Average PO4-P concentration in leachate during the dry year, 1950, for each soil.



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