LEACHING OF NUTRIENTS AND PESTICIDES FROM THE SOIL PROFILE

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Great concern has been expressed in recent years on the possible contamination of our waterways with fertilizers and pesticides originally applied in agricultural endeavours. Ecologists have charged that fertilizers are serious polluters of the environment (8). Considerable anguish was brought to the agricultural community by a proposal made by the Illinois Control Board (22) to limit the amount of nitrogen that can be applied to Illinois cornfields. Data to substantiate these charges and proposals of legislation were not available in many cases. Many immediate investigations of our land management practices will be necessary to find what production practices have to be modified in order to assure that pollution from agricultural sources is kept at a minimum if the nation is to meet the 1985 goal of "the concept of zero – discharge" as conceived by the Environmental Protection Agency (9).

It appears that fertilization practices have affected the nutrient content of some waterways, based on a number of recent research reports. For example, Bingham *et al.* (2) found that both drainage water and nitrate – nitrogen (NO_3–N) losses from a 389 hectare (960 acre) citrus watershed near Riverside, California were substantial, representing 40 to 50% of the water entering the watershed and about 45% of the nitrogen applied each year as fertilizer. Harmeson and Larson (14) and Harmeson *et al.* (15) reported that the nitrate content of surface waters in Illinois sampled prior to 1956 did not exceed the USPS Standard of 45 mg per liter. This standard has since been equalled or exceeded in at least 9 major streams. High nitrate concentrations were associated with areas of intensive agricultural production where soils were well-drained, fertile, rich in organic nitrogen and where high levels of fertilizer nitrogen were applied. Increased nitrate concentrations were correlated with increased stream flow, both reaching maximums during late winter and early spring with minimums attained in late summer and early fall. This pattern would suggest an agricultural source of nitrate as the principal contributor in view of the constancy of seasonal nitrogen outputs from sewage treatment plants.

It has been speculated that nutrient enrichment of waterways would be greatest in areas composed mainly of sandy soils and intensively sprayed and fertilized cash crops such as exist in Florida (19). This speculation appears to be at least partly right when we turn our attention to the results of research studies conducted in Florida. For example, Calvert and Phung (4) reported losses of nitrogen from a newly developed grove near Fort Pierce, Florida of approximately 35% of the applied nitrogen. Forbes *et al.* (12) reported NO_3–N concentration in soil water from both cultivated and uncultivated deep sandy soils of Florida to range from 1 to 17 ppm at the 120-cm depth. The concentrations are similar to the 0.3 to 8 ppm NO_3–N range previously reported (4). Graetz *et al.* (13) in Florida found that approximately 45% of the nitrogen applied to millet planted on Eustis fine sand leached below the root zone. This soil is well-drained and has little biodegradable carbon in the lower horizons, hence it was speculated that microbial denitrification did not occur. Studies conducted by the Central and Southern Florida Flood Control District (7) have shown that average phosphorus concentrations tend to increase with increasing "drainage density". This "drainage density" index is simply the total length of defined waterways (both natural and manmade) within the watershed divided by the watershed area. Drainage density consequently provides a valid general indicator of phosphorus concentrations since the type of agricultural land used is basically the same.

Soil herbicide residue studies conducted by Tucker and Phillips (24) indicate that herbicides used in groves on Florida's deep sands at recommended rates are dissipated to a large extent before reaching ground water levels. Similar studies are in progress on bedded groves in Florida's flatwoods. Wheeler *et al.* (26) found that neither acarol nor chlorobenzilate miticides had significant long-lasting effects on soil microbiological populations and that both chemicals had rapid rates of disappearance from the 2 flatwood soils studied.

The main purpose of my talk today is to review

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the nutrient and pesticide movement studies conducted in conjunction with the SWAP drainage investigation near Fort Pierce, Florida. It will be my pleasure to personally show you our facilities for conducting the SWAP related research for those accompanying us on the Short Course Tour. I would like to briefly explain the SWAP drainage research study in relation to the pesticide and nutrient movement studies for those not remaining for the tour.

The SWAP project is a cooperative research effort of the Agricultural Research Service of the United States Department of Agriculture and the University of Florida Institute of Food and Agricultural Sciences. Its primary objectives were to evaluate systems of water management and tile drain sludge control on Florida flatwood soils (spodosols). The research project is entitled Soil-Water-Atmosphere-Plant relationships (SWAP) and was established by the U. S. Congress in January, 1968. The SWAP drainage study at the ARC Fort Pierce basically is a 25-acre lysimeter study on production and management of citrus groves on tile-drained flatwoods soils.

We took advantage of the highly organized and developed cooperative drainage study to intensify our efforts to investigate the possible losses of pesticides and fertilizer from citrus groves on these types of soils, aided by a research grant sponsored by the Environmental Protection Agency. The SWAP field study was designed to investigate the effect of 3 types of land preparation and 2 drain line designs on the growth of 12 different citrus scion-rootstock combinations. We have a total of 9 plots made up of 3 replications of each of 3 tillage or land preparation treatments. Tillage treatments are DT (deep tillage), DTL (deep tillage plus lime) and ST (surface tillage). Deep tillage was accomplished with a tile trencher to a depth of 106 cm (42 inches) continuously across the landscape for each hectare plot (2.5 acres). Deep-limed plots received 55 tons per ha (25 tons per acre) of dolomitic agricultural limestone before deep mixing.

The objectives of this study are multiple and I will deal today with only those allied to nutrient and pesticide monitoring. Three research objectives along these lines were to 1) monitor the loss of surface-applied fertilizers and pesticides through surface runoff and drainage from a citrus grove located on Florida flatwood soils, 2) establish base-line (background) data for concentration levels of agricultural chemicals for the area under investigation and 3) evaluate the effect of selected carefully defined agricultural management systems upon pollution of soil water.

Now I would like to briefly review with you some of the results we have obtained toward meeting these objectives.

NUTRIENT MONITORING (LONG TERM STUDY)

First, we found that our 2 different types of drain designs, open and submerged drains, had little, if any, effect on nutrient and pesticide movements (4, 25). Nitrate—N concentrations were only slightly lower in submerged lines than in the open drains. Phosphate concentrations and orthophosphate-phosphorus (PO_4—P) discharge were essentially the same from both types of drains.

Our greatest differences and probably most meaningful results from the study have come as a result of the tillage treatments imposed in the SWAP drainage area. Briefly, we have found the nutrient movement resulting from the 3 tillage treatments to be as follows: Greatest leaching losses through the soil profile for both PO_4—P and NO_3—N have occurred from the ST plots. Concentrations of PO_4—P appearing in the drainage water from ST plots were higher than expected and may indicate fixation mechanisms occur to a lesser degree in the A horizons of Oldsmar fine sand than other associated soils (3). Both DT and DTL plots leached very little PO_4—P into drains, apparently due to the greater surface and chemical nature for retention of PO_4—P provided by the deep tillage. The DTL treatment did give significantly more NO_3—N movement into the drains than the DT treatments which was probably due to the higher nitrification rate found for the DTL soil (20).

Not only have concentrations of nutrients in the tile out-flow water varied considerably with tillage treatments, but they have also varied with amount of discharge water, rate and time of fertilization (3) (Table 1) and season (Tables 2 and 3). Monthly NO_3—N concentrations in the drainage water from the SWAP tillage treatments did not exceed 8 ppm in the period May, 1971 through April, 1972. The United States Public Health Service has selected 10 ppm NO_3—N as the critical limit above which water is considered unsafe for drinking purposes (6). Concentrations of PO_4—P in the waters from DT and DTL were very low (0.4 ppm) while concentrations ranged from 0.2 to 0.9 ppm in ST water (3). There was a trend for both NO_3—N and PO_4—P to increase in concentration with increase in rainfall, particularly in the summer months. Nutrient concentrations in drainage water sampled from the surrounding perimeter ditch system and from the drains of a non-tilled non-agricultural (check treatment) area nearby and in the water at the discharge outfall for the overall project generally were much lower than that found in the drainage water from the tilled and cropped areas. The outfall sump water did not exceed 2.5 ppm NO_3—N in the peak period of August, 1971 (unpublished data, Florida Agricultural Experiment Station).

The lower concentration of phosphates in the ditch and outfall can probably be explained by phosphorus fixation with clay materials in the ditch banks and by its absorption by plants in and near the water. There is also a dilution effect caused by water coming from unfertilized areas. Nitrates are probably assimilated by absorption by plants and by denitrification in the near-anaerobic conditions of the ditch bottom. These results are similar to those obtained in a cooperative study between the U. S. Geological Survey and the Central and Southern Florida Flood Control District of the Chandler Slough (7, 17) which indicated that a segment of undisturbed marsh at the lower end of the watershed is effective in reducing the phosphorus concentrations. Phosphorus concentrations were reduced 25% to 55% in the water after flowing through the marsh area.

Total discharge of nutrients is a function of both nutrient concentration and volume of water flow in a given period. I am indebted to E. H. Stewart, USDA–ARS Hydrologist at the SWAP drainage site, for supplying us with a continuous record of water flow from each drain line and for surface runoff values for each tillage plot, as well as a record of the total flow from the overall SWAP area during the periods when the nutrients and pesticides were monitored. Results of the hydrologic studies conducted at the SWAP site have been summarized elsewhere (1, 23). Mean monthly discharges of NO_3–N and PO_4–P in the drainage water were generally greater from the ST treatment than either DT or DTL treatments (3) (Table 1). Peak discharges of both nutrients were obtained during August, 1971, as shown in Figs. 1 and 2; this coincided with a large application of fertilizer prior to establishing a cover crop for erosion control. Mean monthly

Table 1. Fertilizer N, P and K applied/ha and water discharged from 3 tillage treatments.[x]

Date	Fertilizer applied N	P	K	Water discharged[z] ST	DT	DTL
	kg/ha			m³/ha		
1971						
May	3.87	1.69	3.21	222	247	125
June	7.90	3.45	6.56	1,396	790	679
July	7.90	3.45	6.56	768	606	513
August	41.50	18.11	34.45	1,385	816	705
September	10.32	1.13	8.57	604	431	339
October	10.32	1.13	8.57	883	572	541
Mean				876	577	484
1972						
February	10.32	1.13	8.57	767	528	432
April	10.32	1.13	8.57	886	523	397
May	10.32	1.13	8.57	835	572	468
June	15.69	1.73	13.03	3,325	1,689	1,359
July	15.69	1.73	13.03	577	485	388
Mean				1,278	759	609

[x]Reproduced from the Journal of Environmental Quality, 4(2):184, 1975, by permission of the American Society of Agronomy (3)

[z]From records supplied by E. H. Stewart, USDA-ARS, Agr. Res. Center, Fort Pierce, Fl.

Table 2. Mean concentration and drain discharge per month of N, P and K under 3 systems of soil management during May through October 1971.[x,y]

Element	Soil treatment	Concentration Mean[z]	Range	Mean discharge /month[z]
		mg/liter		kg/ha
NO_3–N	ST	5.02 a	0.68–7.88	4.84 a
	DT	2.04 b	0.32–3.15	1.19 b
	DTL	4.07 a	0.75–7.34	2.28 b
PO_4–P	ST	0.63 a	0.47–0.90	0.58 a
	DT	0.27 b	0.10–0.39	0.16 b
	DTL	0.17 c	0.00–0.30	0.10 b
K	ST	7.66 a	4.0–12.4	7.39 a
	DT	6.15 a	4.5– 8.60	3.17 b
	DTL	4.46 a	2.2– 6.50	2.39 b

[x]Reproduced from the Journal of Environmental Quality, 4(2): 185, 1975, by permission of the American Society of Agronomy (3).

[y]High rainfall period.

[z]Means followed by different letters are significantly different (P=0.05), as indicated by Duncan's multiple range test.

Table 3. Mean concentration and drain discharge per month of N, P and K under 3 systems of soil management during November 1971 through April 1972.[x,y]

Element	Soil treatment	Concentration Mean[z]	Range	Mean discharge /month[z]
		mg/liter		kg/ha
NO_3–N	ST	1.51 a	0.40–2.61	0.62 a
	DT	0.72 b	0.43–1.00	0.23 b
	DTL	1.20 a	0.80–2.00	0.29 b
PO_4–P	ST	0.42 a	0.19–0.70	0.16 a
	DT	0.07 b	0.02–0.30	0.02 b
	DTL	0.007c	0.00–0.01	0.01 b
K	ST	2.75 a	1.01–4.10	1.48 a
	DT	3.73 a	2.0 –5.20	1.38 a
	DTL	3.12 a	1.5 –5.20	0.92 b

[x]Reproduced from the Journal of Environmental Quality, 4(2): 185, 1975, by permission of the American Society of Agronomy (3).

[y]Low rainfall period.

[z]Means followed by different letters are significantly different (P=0.05), as indicated by Duncan's multiple range test.

NO_3–N discharges for May through October, 1971 (wet period) amounted to 4.8 kg/ha for ST, 1.2 kg/ha for DT and 2.3 kg/ha for DTL treatments (Table 2); while mean monthly discharges for the low rainfall period of November, 1971 through April, 1972 amounted to 0.6 kg/ha for ST, 0.2 kg/ha for DT and 0.3 kg/ha for DTL (Table 3). Mean monthly PO_4–P discharges were in the order of 0.6 kg/ha for ST, 0.2 kg/ha for DT and 0.1 kg/ha for DTL in the high rainfall period and 0.2 kg/ha for ST, and 0.02 kg/ha for DT and 0.01 kg/ha for DTL in the low rainfall period.

Nitrate-nitrogen losses in the subsurface drainage water from the ST, DT, and DTL plots were equivalent to 31.9, 8.3 and 15% respectively, of the nitrogen applied in the fertilizer (3) (Table 4). Orthophosphate–P losses from the DT and DTL plots were considerably less than from the ST plots. Those losses were equivalent to 14.2, 3.4 and 2.0% of the phosphorus applied to the ST, DT, DTL plots, respectively.

INTENSIVE STUDIES OF NUTRIENT LEACHING

Several short-term intensive studies on NO_3–N, PO_4–P and pesticide losses in both surface and subsurface drainage water from the 3 SWAP tillage systems have been conducted in the past 2 years (5). The pesticide portion of these studies will be summarized separately. These studies were conducted during the drier portions of the years so that we could control the water (irrigation) variable more precisely. Losses were examined after applying irrigations amounting to 12.9, 7.6, 5.6 and 3.8 cm of water and fertilizations amounting to 530 kg per ha of an 8-2-8 (42 kg/ha nitrogen as ammonium nitrate and 50 kg/ha PO_4–P as superphosphate) fertilizer and nominal applications of 2,4-D, chlorobenzilate and terbacil. An exception was the 5.6-cm irrigation period when plots were not treated with fertilizer and pesticides prior to irrigation. The preceding fertilization had been made 2 months prior to the 5.6-cm irrigation. Each intensive study period lasted 14 days, commencing with fertilization and immediately followed by irrigation.

A series of smooth nutrient concentration and discharge curves with well-defined peaks were obtained from these studies (5). Examples of the type of curve obtained by intensive sampling are presented in Figs. 3 and 4 for NO_3–N and PO_4–P discharges in the subsurface drainage water during parts of May and June, 1974 (12.9 cm of irrigation was applied on May 21). We are hopeful that these curves will be useful in the formulation of mathematical models having predictive value for future leaching events.

Surface-tilled plots gave greater NO_3–N discharges (Table 5), 14.4 kg/ha NO_3–N, in the 14-day period after the 12.9-cm irrigation than either DT or DTL, which were 0.6 and 4.8 kg/ha NO_3–N, respectively. Discharges from

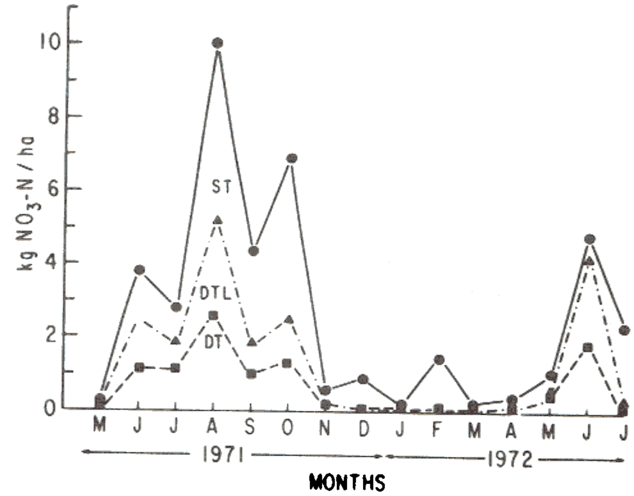

Fig. 1. The effect of 3 soil preparation treatments on NO_3-N discharged in drainage water during May, 1971 through July, 1972. [Reproduced from the Journal of Environmental Quality, 4(2):184, 1975, by permission of the American Society of Agronomy (3)].

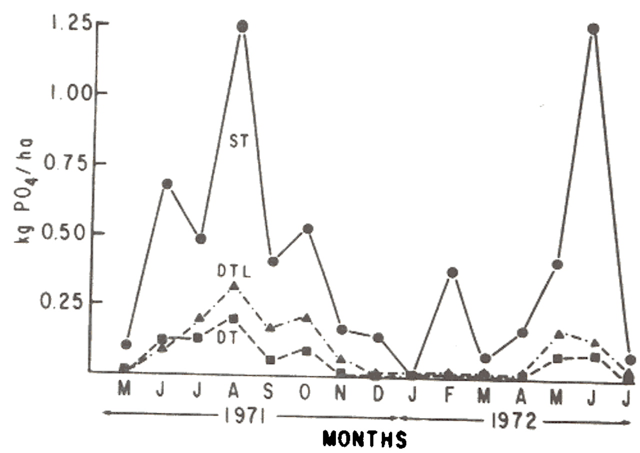

Fig. 2. The effect of 3 soil preparation treatments on PO_4-P (orthophosphates) discharged in drainage water during May, 1971 through July, 1972. [Reproduced from the Journal of Environmental Quality, 4(2):184, 1975, by permission of the American Society of Agronomy (3)].

Table 4. Estimated loss of nutrients in drainage water from plots under 3 systems of soil management expressed as % of total nutrients applied.[z]

Soil treatment	NO_3-N	PO_4-P	K
ST	31.9	14.2	62.3
DT	8.3	3.4	35.5
DTL	15.0	2.0	23.2

[z]Reproduced from the Journal of Environmental Quality, 4(2):185, 1975, by permission of the American Society of Agronomy (3).

DTL were higher, however, than from DT, probably because this mixed and limed soil has a higher nitrification rate, as Phung showed (20). ST plots discharged up to 0.38 kg/ha PO_4–P in the 14-day period following the 12.9-cm irrigation, but phosphate discharges from DT and DTL were only 0.07 and up to 0.11 kg/ha PO_4–P in the 14-day period, respectively (5).

The contribution of surface runoff water to the overall nutrient enrichment of the ditch water was low for the DT plots, less than 0.65 kg/ha NO_3–N for DTL and less than 0.44 kg/ha for DT after the 12.9-cm irrigation, and was zero for ST since there was no runoff from the ST area during any of the irrigation studies (5).

It was especially interesting to find that drainage from the 5.6-cm irrigation without fertilization did not initiate significant discharge of nutrients from the profiles. This tends to indicate that time of fertilization definitely is one of the factors causing enrichment of the tile outflow.

Estimated percentage losses of NO_3–N were sizable from the 12.9- and 7.6-cm irrigations for both ST and DTL treatments (5). ST lost nitrogen equivalent to 34.0% and 12.6%, respectively, of the nitrogen applied in fertilizer while DTL losses were equivalent to 12.9 and 8.3%, respectively, of the applied nitrogen after the 12.9- and 7.6-cm irrigations. Loss of PO_4–P from ST was 3.7 and 1.3% of applied phosphorous and 1.3 and 0.1% from DTL after the 2 irrigations, respectively. Losses of NO_3–N and PO_4–P generally were insignificant for the 5.6- and 3.8-cm irrigations (5).

PESTICIDE MOVEMENT

Water samples collected during each of the intensive study periods were divided into 2 parts, one for nutrient analysis and the other frozen and delivered to Willis Wheeler, Associate Professor in the Food Science Department in Gainesville. Dr. Wheeler was responsible for the determination of pesticide content of the water through gas-liquid chromatography. Pesticides used for this study were chlorobenzilate, a miticide applied to citrus trees and used at a rate of 1.4 kg/ha; 2,4-D applied at a rate of 3.7 kg/ha in a 1-m swath over the "pop up" sprinkler irrigation system at the SWAP site; and terbacil applied at 4.5 kg/ha applied as a 3-m band around the base of the trees. The pesticide-movement results selected for discussion today were collected during and after the 12.9-cm irrigation previously discussed in the nutrient studies. The chemicals listed above were applied on March 5, 1974 and irrigation of the plots started several hours thereafter. Irrigation continued for 39 hours until a total of 12.9 cm of water was applied to the plots. Water samples were taken when flow started in the drains and every 2 hours thereafter for a period of 60 hours; then one sample per day for 7 more days and then 2 samples were collected per week thereafter.

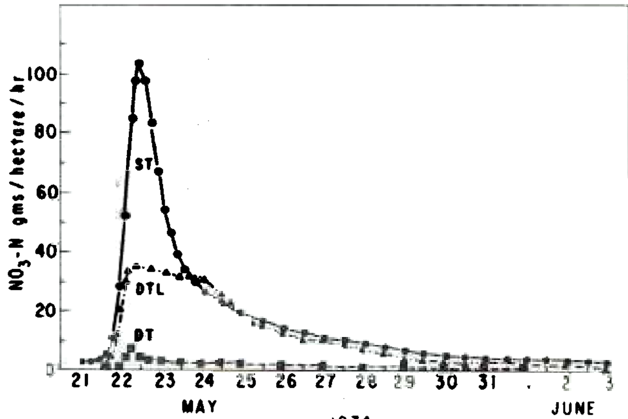

Fig. 3. Leaching response of NO_3-N to regular grove fertilization and 12.9 cm of irrigation. [Reproduced from the Journal of Environmental Quality, 5(2):(In press), 1976, by permission of the American Society of Agronomy (5)].

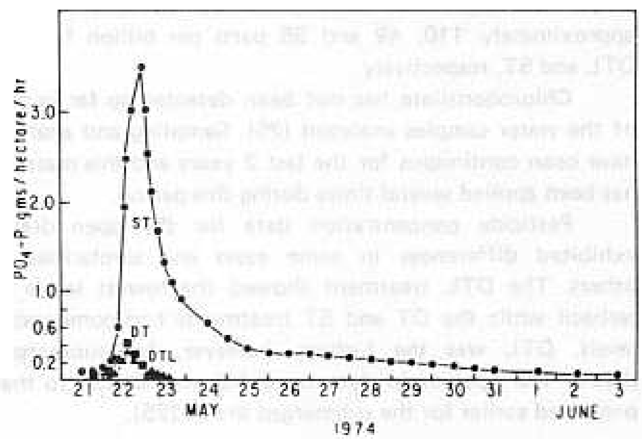

Fig. 4. Leaching response of PO_4-P to regular grove fertilization and 12.9 cm of irrigation. [Reproduced from the Journal of Environmental Quality, 5(2):(In press), 1976, by permission of the American Society of Agronomy (5)].

Table 5. Total discharge of NO_3–N and PO_4–P in subsurface drainage water in response to 4 irrigation amounts.[z]

Soil treatment	Amount of irrigation applied (cm)			
	12.9	7.6	5.6	[illegible]
	kg/ha NO_3–N			
ST	14.4	5.3	2.2	0.9
DT	0.6	0.4	0.001	0.01
DTL	4.8	3.2	0.1	0.09
	g/ha PO_4–P			
ST	388	136	64.0	42
DT	72	5	0.4	Trace
DTL	107	4	3.0	Trace

[z]Reproduced from the Journal of Environmental Quality, 5(2):(In press), 1976, by permission of the American Society of Agronomy (5).

Data obtained during the first 26 hours of sample collection illustrate some trends of how pesticides can migrate downward through soil when applied to the surface of a sandy soil. Terbacil was found in highest concentration in the DTL water initially, and it remained highest throughout the initial 26-hour period (25). ST was initially quite low in terbacil followed by rapid increase over the sampling period, with a peak at 20 hours. The DT treatment remained low and fairly constant in terbacil throughout the the 26-hour period studied. Maximum terbacil found in the drainage water in this study were 124, 110 and 50 parts per billion for the ST, DTL and DTL treatments, respectively.

The DT soil treatment drainage water exhibited a higher 2,4-D concentration than did the other 2 treatments (25). The DTL treatment drainage water showed the lowest concentration; this being sharply divergent from the terbacil situation. Maximum 2,4-D concentrations in the drainage water during the 26-hour period were approximately 110, 48 and 35 parts per billion for DT, DTL and ST, respectively.

Chlorobenzilate has not been detected so far in any of the water samples analyzed (25). Sampling and analysis have been continuous for the last 2 years and this material has been applied several times during this period.

Pesticide concentration data for the open drains exhibited differences in some cases and similarities in others. The DTL treatment showed the lowest levels of terbacil while the DT and ST treatments had comparable levels. DTL was the highest, however, for submerged drains. The open-drain data for 2,4-D was similar to that presented earlier for the submerged drains (25).

RELATED STUDIES CONDUCTED IN THE FIELD, GREENHOUSE, AND LABORATORY

Other studies, both on and off the drainage site but supporting the pesticide and nutrient movement research at the site, have been conducted in several departments on the main campus in Gainesville. These studies are designed to supply information to help explain the differences among treatments obtained at the field site. I would now like to point out a few of the supporting studies that have been carried out.

Phung and Fiskell (21) found that oxygen depletion in poorly-drained soil profiles is followed by denitrification and ferrous iron and manganous-manganese production prior to sulfide production.

Phung (20) found that factors involved in oxidation-reduction changes in the 3 soil modifications were 1) source of organic matter as energy, 2) a rapid loss of nitrate in the top 6 inches of soil compared to a slow loss in the black spodic horizon when the soil is flooded and 3) ferrous iron and hydrogen sulfide development was found to be more rapid in DTL and DT than in undisturbed surface soil and undisturbed spodic (organic hardpan layer) horizon. Phung (20) also found that the oxygen content of the drain outflow water was considerably higher in ST than in DT or DTL and that submerged *vs* open drain outflows were only occasionally different.

Fiskell and Calvert (10) made a comprehensive study of the chemical properties of ST, DT and DTL profiles with sample cores to 10 depths per treatment. Soil cores were 15 cm long and were taken to a depth of 150 cm. They noted that depth of dolomitic lime incorporation drastically affected nitrification and they attributed to nitrate formation the pH changes found after ammonium sulfate incubation. Only 14 tons/ha of free dolomite remained after 2 years from the original 55 tons/ha applied hence they attributed this loss to denitrification and soil reaction which would explain the rather high calcium levels found in the drainage water over this period.

Fiskell and Calvert (10) further showed that redistribution of organic matter from the A (surface) and B_h (organic hard pan) horizons by deep tillage had 25% variability to the 105-cm depth and that the sum of exchangeable cations (field CEC) to the 75-cm depth was in the order DTL > DT > ST.

Studies conducted by Fiskell and Mansell (11) on phosphorous retention showed that deep tillage of the spodosol increased Langmuir maximum sorption from 6 to 96 ppm with a further increase of about 20 ppm for DTL soil. They also noted that phosphorous sorption increased with contact time for the unmixed organic pan, DT and DTL samples, but was most rapid for the unmixed surface horizon and the top of the organic pan horizon. They did not show that incorporation of limestone used in DTL influenced the quality of phosphorous leached from the soil over the DT treatment (without deeply placed limestone).

Kanchanasut (16) in her laboratory investigations of the ST profile showed that sorption of phosphorous by the soil did limit the movement of phosphorous as the soil solution moves through water-saturated cores from the surface (A_1) and spodic (B_{2h}) horizons. Water desaturation tended to decrease the mobility of phosphorous in these 2 horizons even further. Mobilities for phosphorous and chlorine were similar and rapid during water flow through cores from the subsurface (A_2) horizon.

Mansell *et al.* (18) observed in another study using soil from the SWAP site that water-soluble herbicides such as terbacil were very mobile in the A_2 horizon (white sandy layer directly under the surface layer), even for the low concentrations of herbicides applied to the soil.

These are only a few of the studies conducted in conjunction with the SWAP drainage site. There were many other studies conducted in the past few years that are not reported here, especially in relation to the study of water flow through the 3 soil management systems (hydrology).

SUMMARY

Our results from the leaching studies show that drainage of the 3 soil management systems are greatly different. Drainage rates for tile in the ST plots are much higher than for DT and DTL plots. Deep tillage on these soils tends to incorporate clay and organic materials from the subsoil layers into the sandy surface soil, thereby decreasing the hydraulic conductivity of the soil in the root zone. Poorer drainage characteristics of DT and DTL plots provided improved soil-water storage capacities, however. There were also increased cation exchange capacities which in turn resulted in larger growth rates for young citrus trees than those planted in ST plots.

Hydraulic response of the ST soil was particularly rapid and of greater magnitude than for DT and DTL soils. Not only were peak flow rates approximately 2 to 3 times greater for ST drains than for the other drains, but accumulative drainage of water from ST drains was also more than twice that for DT and DTL. Deep tillage of the tile-drained soil appeared to decrease the magnitude of maximum drainage rates and prolong "temporary" soil-water storage over very long periods of time.

Deep tillage of the tile-drained soil appeared to decrease the quantity of NO_3—N leached, and this decrease may be partially due to the net influence of denitrification during transport of NO_3—N through the DT and DTL soils.

Peak loss rates of phosphorous from drain lines coincided with those for nitrogen. As expected, deep tillage drastically decreased leaching losses of phosphorous fertilizer. Unexpectedly however, deep liming of deep-tilled soil did not appear to influence leaching of phosphorous.

These and other data suggest that the tile drainage of this spodosol provides rapid lateral water flow and tends to circumvent flow vertically through the chemically reactive but slowly permeable spodic horizon. The subsurface drainage of this layered spodosol tends to increase leaching losses of fertilizer nutrients.

Deep tillage of the tile-drained soil tended, however, to decrease drainage, increase cation exchange capacity of the A_2 layer and decrease nutrient leaching rates.

Our data show that higher concentrations of nutrients in the drainage water usually followed fertilizations, especially those followed by heavy rainfall. Irrigations of 2 to 3 cm, except where applied excessively for experimental purpose, and low rainfall apparently had little, if any, effect on nutrient concentrations in the drain water. Evidently, a quantity of water above the water holding capacity of the soil is needed, either from rainfall or irrigation to initiate significant nutrient movement.

The higher concentrations of nutrients observed in the drainage water after fertilization contrasts with the low concentrations, nearly zero, observed in water from the check area during identical time periods. The higher overall nutrient content from the grove area would confirm that the agricultural practice of fertilization does increase nitrogen and phosphorous nutrient concentrations in the water. However, the lower concentrations in the perimeter ditch and at the outfall shows that these nutrient concentrations are reduced significantly before being discharged into the drainage canals administered by the Central and Southern Florida Flood Control District.

Rate of water discharge through the drains had a considerable influence upon the discharge of flux for both 2,4-D and terbacil. Scatter in the data is significant, but the flux of either herbicide appeared to increase from zero up to a maximum or peak zone and decrease down to an insignificant value. The discharge of pesticide was almost complete within approximately 2 days after irrigation and closely followed the discharge of drainage water. The magnitude of peak discharge flux for 2,4-D was less than for terbacil. Chlorobenzilate molecules were not detected in the drain water.

Thus, a combination of subsurface drainage and deep tillage appeared to offer the advantages of 1) greater capacity to retain infiltrated water against drainage loss, 2) providing a "buffering capacity" against very fast rates of water table rise during rainy periods, but increasing surface runoff over surface tilled and 3) permitting the maintenance of an aerobic, unsaturated root zone which has a large capacity to attenuate leaching losses of nitrogen and phosphorous, and thus minimize pollution of nearby drainage canals.

LITERATURE CITED

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QUESTIONS

Q: When you were talking about 2.5 times the amount of nitrogen needed, you were referring to mature, bearing trees, weren't you?

Calvert: Yes, because I was speaking of trees producing 500 boxes per acre (50 tons per ha).

Q: What are the standards for nutrient content in water going into drainage ditches and away from the field where it was applied? Aren't some nutrients necessary in the various bodies of water?

Calvert: I'm curious about that myself. The only standards I've seen are those by the U. S. Public Health Service, in which 10 ppm is too high in water to be used for drinking. Beyond that there doesn't appear to be any standard.

Regarding nutrients in the water, we actually fertilize fish ponds to increase fish size and numbers. The shellfish industry depends on nutrient-rich water, and the reason it isn't so good around Ft. Pierce is because the drainage water is flushed out of the area by the inlet. So we may be trying to prevent something that may prove detrimental in the long run. We do need to know what levels are satisfactory or even necessary.

Ecologists are concerned about nitrates and phosphates in runoff water because of eutrophication or dying of lakes, due to sedimentation of algae and other organic matter which grows profusely under conditions of high nutrient levels in the water. Whether man is doing very much to accelerate this process remains to be seen. Certainly, man appears to have some influence on it.

Q: In the application of fertilizer, would there be a greater loss of nutrients from liquid or dry formulations?

Calvert: This is purely a guess, but I would think there would be less loss from liquid fertilizer. The reason is that the liquid fertilizer could penetrate the soil 1 cm or so before it dried, while the dry fertilizer would still be sitting in granular form on the soil surface. Too, subsequent rain or irrigation would have to dissolve the nutrients in granular form before soil infiltration. Thus, the liquid fertilizer would appear to be better distributed and thus better utilized by the plant.