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Evaluation Of Non-Point Pollution Control Practices And Copper Treatments On Control Of Nuisance Filamentous Algae

C. A. Lembi

D. F. Spencer

S. W. O'Neal

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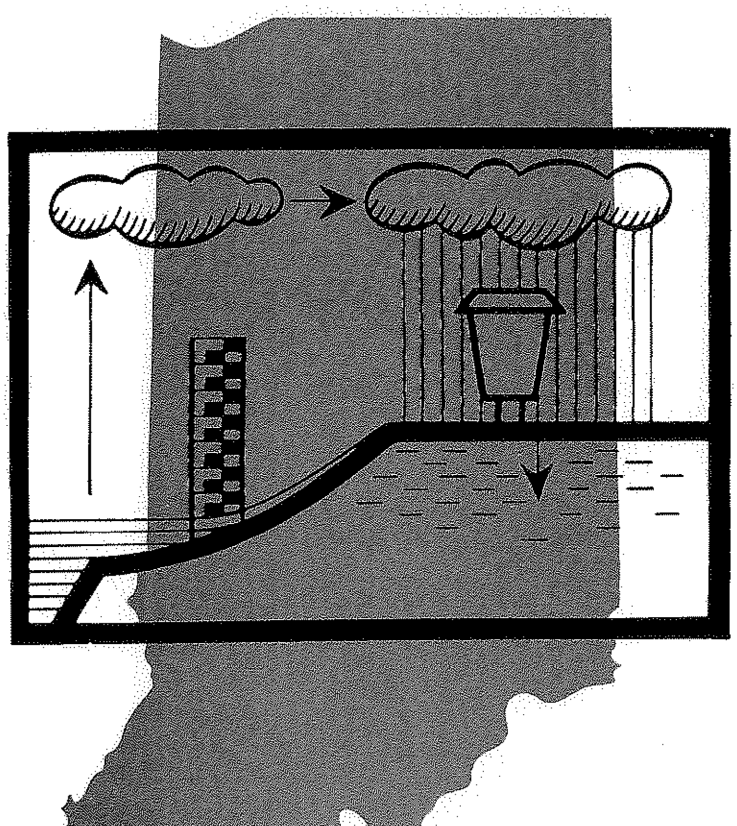
TECHNICAL REPORT 170

EVALUATION OF NON-POINT POLLUTION CONTROL PRACTICES AND COPPER TREATMENTS ON CONTROL OF NUISANCE FILAMENTOUS ALGAE



by

Carole A. Lembi
David F. Spencer
and
Steven W. O'Neal

December 1984

PURDUE UNIVERSITY
WATER RESOURCES RESEARCH CENTER
WEST LAFAYETTE, INDIANA

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Carole A. Lembi

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Project personnel were Carole A. Lembi (Professor, Purdue University), David F. Spencer (formerly at I.U.P.U.I. at Indianapolis; currently at the USDA/ARS Aquatic Weed Research Lab at the University of California, Davis), and Steven W. O'Neal (Postdoctoral Associate).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Runoff studies were initiated in May 1984 on an erodible soil with slopes ranging from 4.6 to 13.8%. 100 ft^2 plots were divided into two tillage treatments: 1) no-till and 2) conventional plow system. Within each tillage treatment, three nitrogen application techniques were used: 1) surface application of ammonium nitrate pellets (33.5% N), 2) injected anhydrous ammonia, and 3) injected anhydrous ammonia stabilized with the nitrification inhibitor nitrapyrin. A fourth set of plots was left unfertilized. All application rates were at 200 lbs nitrogen per acre. Two light rainfalls of 1.4 inch and 0.2 inch were followed a month later by a heavier rainfall of 2.5 inches.

Runoff of water from the plots was related more closely to tillage system than to either % slope or nitrogen application technique. Runoff of water, NH_3-N, and NO_3-N was greater from the no-till plots than from the conventional till plots during the first rainfall event (1.5 inch). More nitrogen was lost from the conventional till plots than the no-till plots during the later, heavier rainfall event of 2.5 inches. This also concided with a significantly greater loss of filterable solids from the conventional till plots. The only significant effect of nitrogen application technique on nitrogen runoff was a greater amount of NH_3-N in the runoff from surface applications (in both conventional and no-till plots) at the 2.5 inch rainfall date. No differences could be detected in the runoff of NH_3-N or NO_3-N from untreated control, injected nitrogen, or stabilized injected nitrogen plots.

Calculations of nutrient loading in Surrey Lake, Indiana based on the runoff data suggest that conversion of the agricultural land in the watershed from a conventional till, anhydrous ammonia injected management system to a no-till system with either anhydrous ammonia injected alone or injected with nitrapyrin should lead to a reduction (46% and 49%, respectively) in concentrations of inorganic nitrogen. Simulations using a computer model for growth of the nuisance filamentous alga *Pithophora* in Surrey Lake show that nitrogen reductions of this magnitude would result in noticeable reductions (approximately 40%) in *Pithophora* biomass production over a growing season. The analysis further suggests that use of conventional tillage in combination with injected ammonia with nitrapyrin or surface applications of ammonium nitrate would lead to increased growth of *Pithophora*.

Studies on the response of *Pithophora* to the algicide copper sulfate suggest that the tolerance of the alga to midsummer applications is due partially to lack of copper penetration into the thick mats. Evidence is presented suggesting that early season treatments at water temperatures of 10 C and when biomass is low would be efficacious at high copper doses.

INTRODUCTION

One of the major consequences of nutrient inputs into lakes and streams is the excessive growth of algae and other aquatic weeds. These plants in turn cause fish kills and limit or prevent the use of water for recreation, fish culture, irrigation, and many other purposes. One of the most serious weeds in Indiana and the midwest is *Pithophora*, a green alga that forms thick floating mats of filaments. This organism is of concern because of its reported resistance to standard algicides. We became involved in *Pithophora* research several years ago when the property owners associations of Lakes Wawasee and Syracuse, major recreational areas in northeastern Indiana, found that they could not control the alga using standard techniques. Lake owners and commercial applicators from Ohio, Michigan, and Wisconsin have also reported serious and uncontrollable infestations of *Pithophora* in their areas.

Most of these lakes as well as ponds and streams throughout the region are impacted by nonpoint sources of nutrients, primarily from runoff from agricultural land, which promote algal growth. Much recent emphasis has been placed in evaluating and developing land use practices to reduce the movement of sediment into these waters. No-till and other conservation tillage practices have been shown to reduce soil erosion thereby decreasing the total amount of nutrient entering the water. However, nitrogen fertilizers in no-till are frequently applied to the soil surface as broadcast treatments of ammonia compounds and urea. Nitrogen applied in this manner is susceptible to surface runoff with the first heavy rain. An alternative method of handling nitrogen in no-till is to inject it (in the form of anhydrous ammonia) into the soil. This technique theoretically should reduce nitrogen runoff. Injection equipment for no-till has recently been developed and interest in the technique appears to be increasing. A relatively recent modification in injection on both conventional tillage and no-till has been to "stabilize" the nitrogen by adding nitrification inhibitors. These compounds reduce the loss of nitrogen from the crop root zone by preventing the conversion of ammonia to nitrate, the form most susceptible to soil leaching. Because of the longer persistance of ammonia when nitrification inhibitors are added, the potential exists for more nitrogen to enter runoff when soil erodes than there would be if the ammonia had been converted to nitrate and leached into the soil.

The impact of each of these relatively new technologies on receiving waters and algal growth has not yet been evaluated. Since nutrient control offers the most consistent, long-term control for nuisance algae, it is important to determine the relative value of these agricultural management practices in reducing nutrient input into receiving waters. The significance of using Pithophora to evaluate the impact of tillage systems and nitrogen application technique on receiving waters is due to the potential of the alga to be nitrogen limited in the open waters of shallow lakes (Spencer and Lembi, 1981). Thus, in areas receiving large inputs of nitrogen from agricultural practices, Pithophora growth is likely to occur. The availability of a computer model for Pithophora growth that incorporates responses to nitrogen and phosphorus inputs and evaluates them on the basis of runoff data provides a unique opportunity to predict the impact of land management practices on algal growth.

The other approach to algal control is through the use of algicides. Although providing only temporary solutions to the problem, algicides are often the only means by which lake and pond owners can seek immediate relief from algal infestations. Copper sulfate is effective in controlling most species of filamentous algae. Pithophora, however, appears to be tolerant to the compound. Studies in our laboratory show that the susceptibility of the alga to copper varies according to the stage in the life cycle. Field testing in which copper treatments are applied to coincide with life cycle stages and certain environmental parameters offers another approach to the control of this nuisance alga.

The major portion of this report is devoted to the analysis of tests of runoff from plots comparing tillage treatments (conventional and no-till) and nitrogen application techniques (surface-applied, injected, and stabilized injected). A description of how runoff data can be used in the Pithophora growth model to predict the impact of watershed management strategies is given. The last section of the report is a description of laboratory and field experiments on efficacy of copper treatments when made at different life cycle stages and water temperatures.

RUNOFF STUDIES

Materials and Methods. Field plots for runoff tests were established on the Agnes Demaree farm east of Madision, IN on land leased for a USDA cooperative project with Purdue University to study integrated pest management systems. The major soil type on this farm is a Ryker silt loam, a highly erodible soil. A total of 64 runoff plots were established on slopes ranging from 4.6 to 13.8%.

Each plot consisted of a 100 ft^2 block bordered by 2 X 4 X 10 inch wood planks anchored with metal rods into the ground. Soil was tapped along the outside edges to prevent entry of runoff water from outside the plot. Gullies also were dug around each enclosure to divert outside runoff away from the plot area. Four inch diameter PVC pipe was used to direct runoff water from inside the plot area to a 5 foot diameter plastic pool sunk into the ground (Figure 1). The pipe was placed at the lowest point in the enclosure to insure collection and movement of runoff toward the pool.

The plots were divided into two tillage treatments: 1) no-till and 2) conventional plow system. Within each tillage treatment, three nitrogen application methods were used: 1) surface application of ammonium nitrate pellets (33.5% N), 2) injected anhydrous ammonia, and 3) injected anhydrous ammonia stabilized with the nitrification inhibitor nitrapyrin. A fourth set of plots was left unfertilized. All application rates were at 200 lbs nitrogen per acre. Each combination of tillage treatment and nitrogen application method was replicated 8 times (see Figure 2 for plot layout). A separate pool was set out to collect rainwater for background concentrations of nutrients. Four rain gauges were also placed in the plot area.

Replicates 1 to 5 were established in corn stubble fallowed for one year. Replicates 6 to 8 were established in no-till wheat stubble following conventional tilled corn. In all replicate sets except 8, the corn or wheat rows were at right angles to the slope. The conventional tillage plots were moldboard plowed once followed by a single pass with a disk. The tillage and nitrogen injection equipment also was operated at right angles to the slope. Nitrogen injection was with standard anhydrous knives on 30 inch centers at an

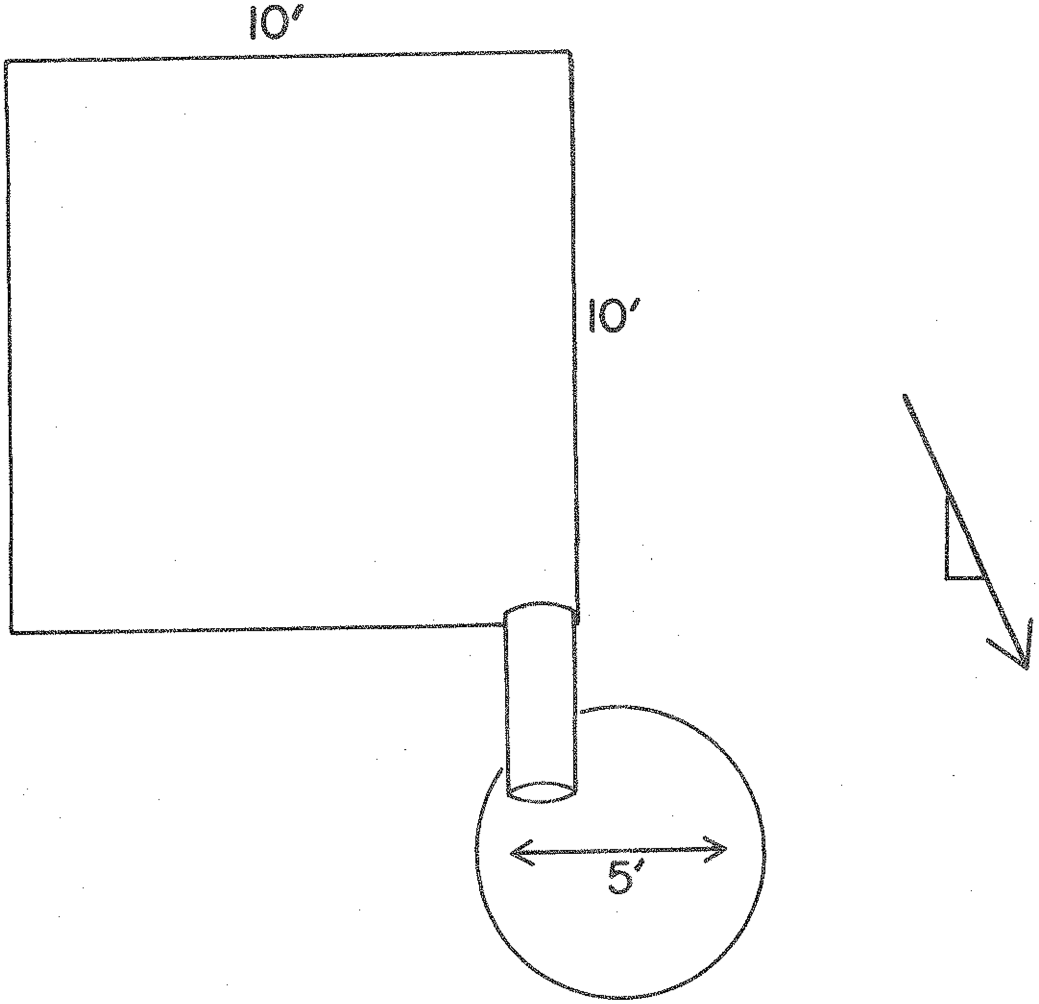

Figure 1. Runoff collection system (pipe not drawn to scale).

Legend for Figure 2

Conventional Till Plots

CC = unfertilized control

CS = surface application of nitrogen

CI = injected nitrogen

CIS = injected stabilized nitrogen

No-till Plots

NC = unfertilized control

NS = surface application of nitrogen

NI = injected nitrogen

NIS = injected stabilized nitrogen

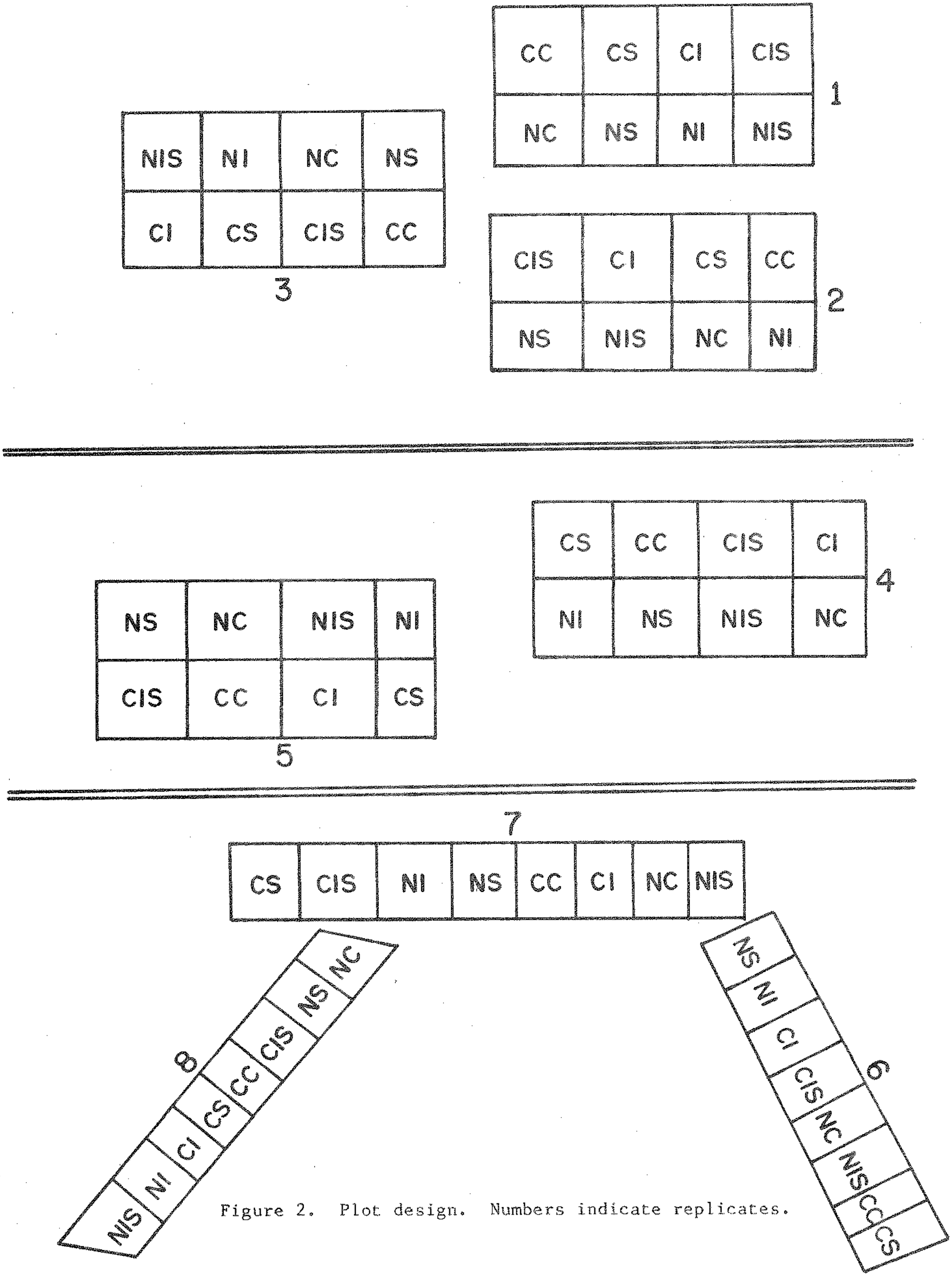

Figure 2. Plot design. Numbers indicate replicates.

injection depth of 8 inches. Injection slits (but no nitrogen) were also made in the control (unfertilized) plots and the plots receiving surface applied pellets.

All collection pools were set in place between May 15 and 16. The plowing of the conventional tillage areas was done on May 17. All nitrogen applications were made on May 18. The boards to enclose the 100 ft^2 plot areas in the treated and control areas were set in place on May 19 and 20.

Runoff samples were collected from each pool within 24 hours after a measureable rain. Four collections were made: 1) May 23 following a 1.4 inch rain, 2) May 26 following a 0.5 inch rain, 3) May 30 following a 0.2 inch rain, and 4) June 25 following a 2.5 inch rain. Water was also collected from the rainwater pool. The water in each pool was vigorously stirred to suspend sediments during collection. Polyethylene bottles were used to collect a one liter sample from each pool. The samples were iced immediately, returned to the laboratory, and frozen. Following sample collection, the amount of runoff water in each pool (including the rainwater pool) was measured and then discarded.

Runoff and rainwater samples were analyzed for suspended (filterable) solids by filtering 50 ml samples on preweighed Whatman #1 filter paper (pore size 10 uM), drying the samples to constant weight at 105 C, and weighing. Total nitrogen and total phosphorus were determined for unfiltered and filtered (0.44 um Milipore filter) samples. All other analyses were conducted on Millipore filtered samples. NH_3-N, NO_2-N, soluble reactive PO_4-P(SRP), and total phosphorus were determined according to methods described in Wetzel and Likens (1983). NO_3-N was measured using an Orion NO_3 ion electrode, Model 93-07. Total nitrogen was determined using the persulfate digestion method of Raveh and Avnimelech (1979).

Unless otherwise indicated, all data are expressed as mg/plot (plot = 100 ft and were obtained using the following formulas:

Rainwater: Amt. water in rainwater pool (l) x mg/l nutrient = total mg nutrient

Runoff: Amt. water in runoff pool (l) x mg/l nutrient = total mg nutrient

Total mg (runoff) - Total mg (rainwater) = mg nutrient/plot

Results

Data from three of the four runoff collection dates (23 May, 1.4 inch; 30 May, 0.2 inch; and 25 Jun, 2.5 inch) are summarized here. All original data are presented in Appendices A and B.

Slope varied from 4.6 to 13.8%, with a mean of 8.4% (SD = 2.1%). Analysis of variance revealed that slope did not differ significantly among treatments ($P>0.05$).

All data discussed below are presented as treatment means using only those plots in which the amount of water collected in the runoff pool was greater than that collected in the rainwater pool for that date.

A summary of a two-way analysis of variance is presented in Table 1. The most significant effects ($P<0.05$) were those of tillage system on runoff water, NH_3-N, total filtered and unfiltered N, and total unfiltered P at the 23 May date and on runoff water, NH_3-N, NO_3-N, total filtered and unfiltered N, and filterable solids on the 25 June date. An effect of nitrogen application method was detected on total unfiltered P on 23 May and on NH_3-N on 25 Jun. No

TABLE 1. Summary of two-way ANOVA comparing measured variables with tillage system and nitrogen application method.

Date	Variable	Tillage syst.	N-appl.	Tillage X N-appl.
23 May	Runoff (l)	**	NS	NS
	NH_3-N	*	NS	NS
	NO_2-N	NS	NS	NS
	NO_3-N	NS	NS	NS
	Total N (F)	*	NS	NS
	Total N (U)	*	NS	NS
	Total P (F)	NS	NS	NS
	Total P (U)	*	*	NS
	SRP	NS	NS	NS
	Filt. Solids	NS	NS	NS
30 May	Runoff (l)	NS	NS	NS
	NH_3-N	NS	NS	NS
	NO_2-N	NS	NS	NS
	NO_3-N	NS	NS	NS
	Total N (F)	NS	NS	NS
	Total N (U)	NS	NS	NS
	Total P (F)	NS	NS	NS
	Total P (U)	NS	NS	NS
	SRP	NS	NS	NS
	Filt. Solids	NS	NS	NS
25 Jun	Runoff (l)	***	NS	NS
	NH_3-N	**	*	NS
	NO_2-N	NS	NS	NS
	NO_3-N	***	NS	NS
	Total N (F)	*	NS	NS
	Total N (U)	*	NS	NS
	Total P (F)	NS	NS	NS
	Total P (U)	NS	NS	NS
	SRP	NS	NS	NS
	Filt. Solids	***	NS	NS

* = $P<0.05$; ** = $P<0.01$; *** = $P<0.001$

U = unfiltered; F = filtered

significant interactions between tillage system and nitrogen application method were found.

Means of water runoff, NH_3-N, NO_3-N, total filtered and unfiltered phosphorus, soluble reactive phosphorus (SRP), and filterable solids for the two tillage systems are presented in Table 2. The amount of runoff water per plot was significantly greater on the no-till plots than the conventional till plots at the first collection date. The same trend was noted at the 30 May date. However, on 25 Jun, the trend was reversed, with more runoff water being collected from the conventional till plots than the no-till plots. Another indication of this general pattern was the number of plots from which runoff in excess of rainwater was collected. On 23 May, runoff was collected from only 10 of 32 conventional till plots but from 18 of 32 no-till plots. On 30 May, runoff was collected again from 10 of 32 conventional till plots but from twice as many no-till plots (20 of 32). On 25 Jun, with the heavier rainfall, the number of plots with runoff was about even with runoff being collected on 28 of 32 conventional till plots and 26 of 32 no-till plots. The total amount of runoff was highest at the 25 Jun date for both no-till and conventional plots.

The same trend was observed for NH_3-N and NO_3-N runoff: higher amounts were found in the runoff from the no-till plots than from the conventional plots on the first two collection dates. On the 25 June date, significantly higher values of NH_3-N and NO_3-N were monitored in the runoff from the conventional till plots than in the runoff from the no-till plots. Although both NH_3-N and NO_3-N runoff was higher in the conventional till plots on 25 Jun, the amount per plot (45.34 mg and 58.91 mg, respectively) was generally lower than the

TABLE 2. Means of selected variables for runoff from conventional till and no-till systems.

	23 MAY	30 MAY	25 JUN
		--Runoff (l/plot)--	
Conventional till	1.10	0.79	29.21
No-till	8.63	3.23	11.51
		--NH_3-N (mg/plot)--	
Conventional till	5.50	3.93	45.34
No-till	191.19	36.16	18.88
		--NO_3-N (mg/plot)--	
Conventional till	5.80	11.60	58.91
No-till	327.80	273.30	21.30
		--Total P filt. (mg/plot)--	
Conventional till	0.00	0.11	0.65
No-till	0.94	0.05	0.89
		--Total P unfilt. (mg/plot)--	
Conventional till	1.16	0.17	8.19
No-till	3.72	0.42	7.43
		--Soluble reactive P (mg/plot)--	
Conventional till	0.00	0.00	0.39
No-till	0.42	0.09	0.86
		--Filterable solids (g/plot)--	
Conventional till	88.50	16.19	165.24
No-till	63.73	11.35	70.55

amount that ran off the no-till plots on 23 May (191.19 mg NH_3-N and 327.80 mg NO_3-N).

Means of NH_3-N and NO_3-N runoff at the three dates according to nitrogen application method are shown in Table 3. Surface applications of ammonium nitrate resulted in the highest runoff levels at all three dates. NH_3-N runoff from surface applications was significantly higher than from other application methods on the 25 Jun date ($P<0.05$). Although tillage system had no statistically significant effect on the amount of runoff from surface nitrogen applications, the means of no-till surface applications at both the 23 May and 30 May dates were considerably higher than the means of the conventional till surface applications (Table 4) although considerable variation exists in the data for these dates.

Phosphorus was not applied to any of the plots in 1984 and was detected only at very low levels in the runoff. In general, it appeared as though slightly more of the phosphorus present moved off the no-till plots than the conventional till plots (Table 2) although statistically, tillage system had a significant effect only on unfiltered total phosphorus at the 23 May date.

Movement of filterable solids in the runoff was generally greater from the conventional till plots than the no-till plots (Table 2). A highly significant difference was noted at the 25 Jun date.

A summary of the means of selected variables for each tillage treatment and nitrogen application method at the three collection dates is provided in Table 4.

Phosphorus was not applied to any of the plots in 1984 and was detected only at very low levels in the runoff. In general, it appeared as though

TABLE 3. Means of NH_3-N and NO_3-N in runoff from plots with different nitrogen application methods.

	23 MAY	30 MAY	25 JUN
		--NH_3-N (mg/plot)--	
Surface application	326.10	86.99	55.38
Injected	135.40	9.07	18.45
Injected stabilized	60.10	10.40	40.89
Unfertilized control	5.20	0.24	17.90
		--NO_3-N (mg/plot)--	
Surface application	857.10	737.00	59.43
Injected	64.70	23.80	37.55
Injected stabilized	41.50	21.30	40.79
Unfertilized control	0.90	7.70	26.76

TABLE 4. Means of selected variables for runoff from each combination of tillage system and nitrogen application method.

	mg/plot				g/plot
	NH_3-N	NO_3-N	TP-U	SRP	Filt. Solids
23 MAY					
Conventional					
Surface	1.45	0.00	0.00	0.00	47.34
Injected	4.20	0.00	2.43	0.00	119.39
Injected-st.	7.59	19.19	0.83	0.00	79.84
Control	6.06	0.00	0.62	0.00	80.01
No-till					
Surface	391.07	1028.56	4.35	0.67	65.25
Injected	214.04	103.51	7.00	0.14	68.21
Injected-st.	99.49	58.29	2.23	0.05	34.92
Control	4.47	1.65	0.32	0.00	85.03
30 MAY					
Conventional					
Surface	10.38	15.30	0.47	0.00	8.81
Injected	0.82	3.18	0.12	0.00	20.79
Injected-st.	11.97	41.74	0.25	0.00	17.88
Control	0.55	1.80	0.08	0.00	11.39
No-till					
Surface	99.76	857.26	0.51	0.08	13.03
Injected	13.79	35.52	0.37	0.09	11.95
Injected-st.	9.36	8.06	0.61	0.00	4.52
Control	0.01	12.20	0.23	0.19	11.19
25 JUN					
Conventional					
Surface	72.83	77.69	8.18	0.00	177.61
Injected	25.17	60.12	5.74	0.84	185.74
Injected-st.	60.15	64.89	12.07	0.37	170.97
Control	16.38	30.42	6.45	0.46	127.81
No-till					
Surface	27.46	30.23	7.52	0.18	123.30
Injected	13.40	20.63	6.99	1.04	51.12
Injected-st.	18.42	12.67	12.86	1.57	46.75
Control	19.41	23.10	4.31	0.54	75.49

slightly more of the phosphorus present moved off the no-till plots than the conventional till plots (Table 2) although statistically, tillage system had a significant effect only on unfiltered total phosphorus at the 23 May date.

Movement of filterable solids in the runoff was generally greater from the conventional till plots than the no-till plots (Table 2). A highly significant difference was noted at the 25 Jun date.

A summary of the means of selected variables for each tillage treatment and nitrogen application method at the three collection dates is provided in Table 4.

Discussion

Runoff of water from the plots was related more closely to tillage system than to either % slope or nitrogen application method. Initial runoff was greater from no-till plots than conventional till plots following light rains of 1.4 and 0.2 inches. This was probably due to the greater firmness of the no-till soil surface in comparison to the recently plowed and upturned surface of the conventional till plots. A later heavier rain of 2.5 inches resulted in significantly greater runoff from the conventional till plots than from the no-till plots. This is probably a consequence in part of the erodibility of the water saturated plowed ground and was also reflected in the significantly greater loss of soil from the conventional till plots than the no-till plots on this date.

Runoff of NH_3-N and NO_3-N following the two light rains was also considerably greater from the no-till plots than the conventional till plots. The trend was reversed at the 25 Jun date after the heavy 2.5 inch rain with means of 45.34 mg and 58.91 mg NH_3-N and NO_3-N, respectively, in runoff from the conventional till plots and 18.88 mg and 21.30 mg, respectively, in runoff from the no-till plots. Ammonia tie-up to soil colloids probably accounts for the fact that ammonia did not move off the conventional till plots until considerable soil loss had also occurred. Additionally, nitrate would tend to be leached in to plowed, loose soil with light rains and also would not move off conventionally tilled ground until significant soil movement occurred. It is interesting that the NO_3-N appeared to remain on the soil surface in the no-till plots through both the 23 May and 30 May dates. It was not until a heavy rain occurred that the nitrate apparently was able to leach into the soil in these plots. Soil samples prior to and after each rain event were taken for NH_3-N and NO_3-N analyses to determine nitrogen distribution and loss, but the results were not yet available at the time of this writing.

Amounts of NH_3-N and NO_N in the runoff from the conventional till plots on 25 Jun were lower than the amounts that moved from the no-till plots on the first two dates, even though water runoff was greater on the 25 June date. Since the highest initial nitrogen levels as well as greatest loss over time was from surface application of ammonium nitrate to no-till plots, the values over the three dates probably reflect the gradual loss of nitrogen from the surface, either through leaching or initial runoff.

NH_3-N and NO_3-N runoff from the unfertilized control plots and the phosphorus runoff in general appeared to be more directly related to rainfall and the amount of water runoff over the three dates (e.g., see total unfiltered phosphorus in Table 2). Residual N and P in untreated soils and plant residues would be more likely to move off plots proportionally to rainfall and runoff fluctuations than would N and P from surface treated plots.

No significant difference was noted in NH_3-N and NO_3-N runoff from unfertilized control, nitrogen injected, and stabilized nitrogen injected plots. An examination of the means from the no-till plots on 23 May and 30 May (Table 4) suggests that more runoff may have occurred from the nitrogen injected and stabilized nitrogen injected plots than from the unfertilized controls; however, by the 25 Jun date no differences between controls and injected treatments were visible in the no-till plots. By this date, levels of NH_3-N and NO_3-N runoff in general appeared to be slightly higher from the conventional till plots than from the no-till plots, again probably reflective of the greater water and soil runoff from the conventional plots on this date.

PITHOPHORA GROWTH MODEL

Description of the Model

The growth model described here is based on modifications to the Monod function described by O'Brien (1974). O'Brien stated that growth of a number of algal species could be described by the Monod equation:

$$g = G_m \frac{C}{C + K_s} \qquad (1)$$

where g = the growth rate

G_m = the maximum growth rate

C = the concentration of the nutrient limiting growth

K_s = the half saturation constant, the concentration of nutrient at which the growth rate equals one-half the maxiumum growth rate

O'Brien modified this equation by including a term, d, to account for algal mortality (eq. 2) and by incorporating a second equation (eq. 3) to describe nutrient dynamics as growth occurred.

$$g = G_m \frac{C}{C + K_s} - d \qquad (2)$$

$$\frac{dC}{dt} = R - DN_g \qquad (3)$$

where N = algal biomass

R = the rate of replacement of the limiting nutrient

D = the depletion factor or percent cell composition of the limiting nutrient

O'Brien suggested that equations 2 and 3 constituted the simplest set of equations that could be used to desribe many observed growth characteristics of phytoplankton species.

Our initial attempts to model *Pithophora* growth were based on equations 2 and 3. However, these equations do not take into account temporal changes in the nutrient that is limiting growth. Since our previous studies (Spencer and Lembi, 1981) indicated that nitrogen limitation can play as important a role in regulating the spatial distribution of *Pithophora* as phosphorus, a method was developed to determine when nitrogen or phosphorus is limiting growth and was incorporated into the model.

A flow diagram of the model is shown in Figure 3. An important feature is the method for determining whether N or P limits growth for a given time interval. This is done by calculating the appropriate temperature dependent K_s and G_m (umax) values (predetermined in the laboratory on algal cultures) for N- and P-limited growth. Next, the ratio of N/P in the lake water is determined. Tilman (1977) suggested that in a chemostat at steady state an alga would be limited by two nutrients when the ratio of the nutrient concentrations is equal to the ratio of the Ks values for those nutrients:

$$N/P = K_{s(N)}/K_{s(P)}$$

If, however, $N/P > K_{s(N)}/K_{s(P)}$, then P is the limiting nutrient. Conversely, N limits growth when $N/P < K_{s(N)}/K_{s(P)}$. While it is unlikely that steady state growth of algae occurs in nature, there is ample evidence that this approach may be useful in predicting nutrient limitation for *Pithophora* (Spencer and Lembi, 1981) and other algal species (Tilman, 1977). The model calculates the appropriate ratios and uses the equation for N- or P-limited growth as indicated.

Since *Pithophora* is a free-floating alga, it is susceptible to loss of biomass from washout in shallow lake basins, a condition that often occurs with heavy rainfall. Thus, the model includes modifications for washout effects. This was done by using the Soil Conservation Service runnoff equation (USDA, 1975) to calculate the amount of runoff that would result for a given amount of rainfall in the lake drainage area. The rainfall data (cumulative totals for 15 day periods) are normalized to 2 year 24 hour rainfall by assuming that the

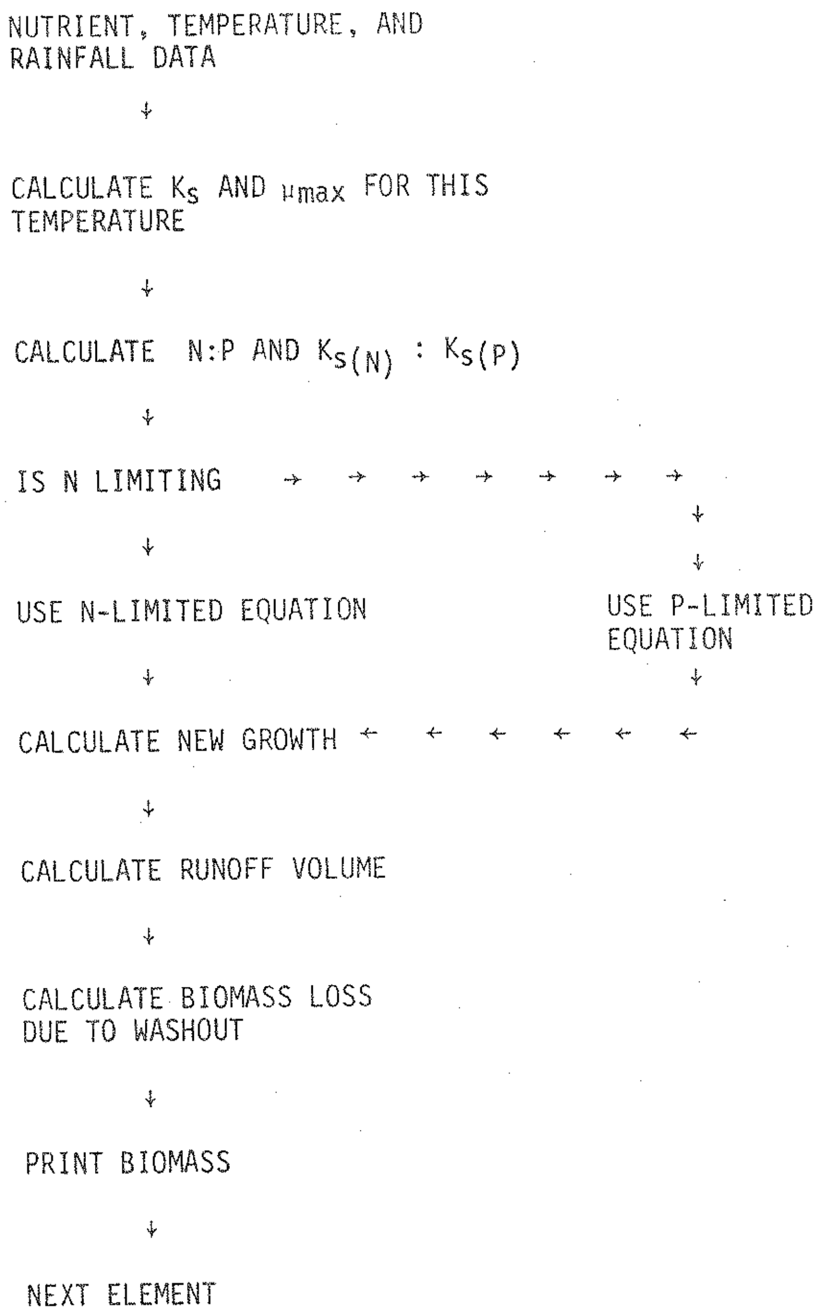

Figure 3. Flow diagram of *Pithophora* growth model.

highest value measured during the year was the 2 year 24 hour rainfall. The value for each 15 day period was divided by the maximum value and the resulting fraction multiplied by the 2 year 24 hour rainfall to give the relative rainfall during a 2 week interval.

The model has been run to simulate Pithophora biomass production in Surrey Lake, our study lake in central Indiana. The model predictions and actual measured biomass values are shown for two years, 1979 (Figure 4) and 1981 (Figure 5). The sharp decline in midsummer, 1979 in actual biomass (and as predicted by the model) was due to the washout phenomenon mentioned above.

The growth model not only appears to be generally capable of simulating the production of Pithophora biomass but can also be used to assess Pithophora response to reduced nutrient concentrations. Simulations in which either NO_3-N or total P were reduced by 50% were executed. The results (Figure 6) show that a greater reduction in biomass would result if NO_3-N were reduced by 50% than for a similar reduction in total P. These results suggest that management actions designed to prevent entry of nitrate (or ammonia) into Surrey Lake would lead to the greatest decrease in Pithophora growth and underscore the importance of seeking tillage systems that would prevent the downslope movement of these nutrients.

Predicted Growth of Pithophora under Different Management Systems

The potential impact of the use of different combinations of tillage system and nitrogen application technique on the growth of Pithophora can be assessed as a first approximation by combining the results of the runoff study with the model for Pithophora growth in Surrey Lake. The following assumptions are implicit in this analysis:

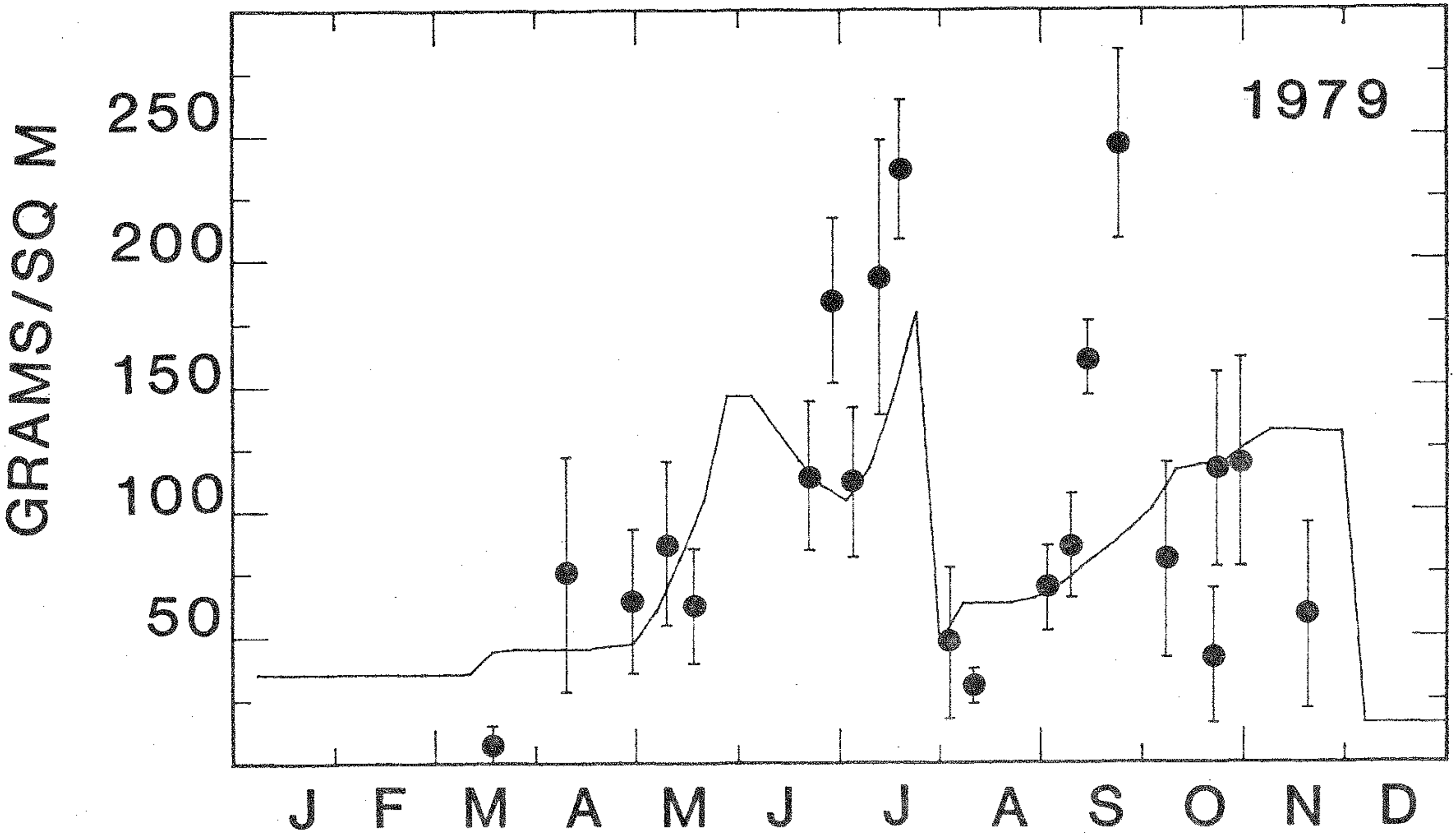

Figure 4. Model estimate (solid line) of *Pithophora* growth in Surrey Lake for 1979. Solid circles represent measured biomass levels. Error bars are ±1 SE.

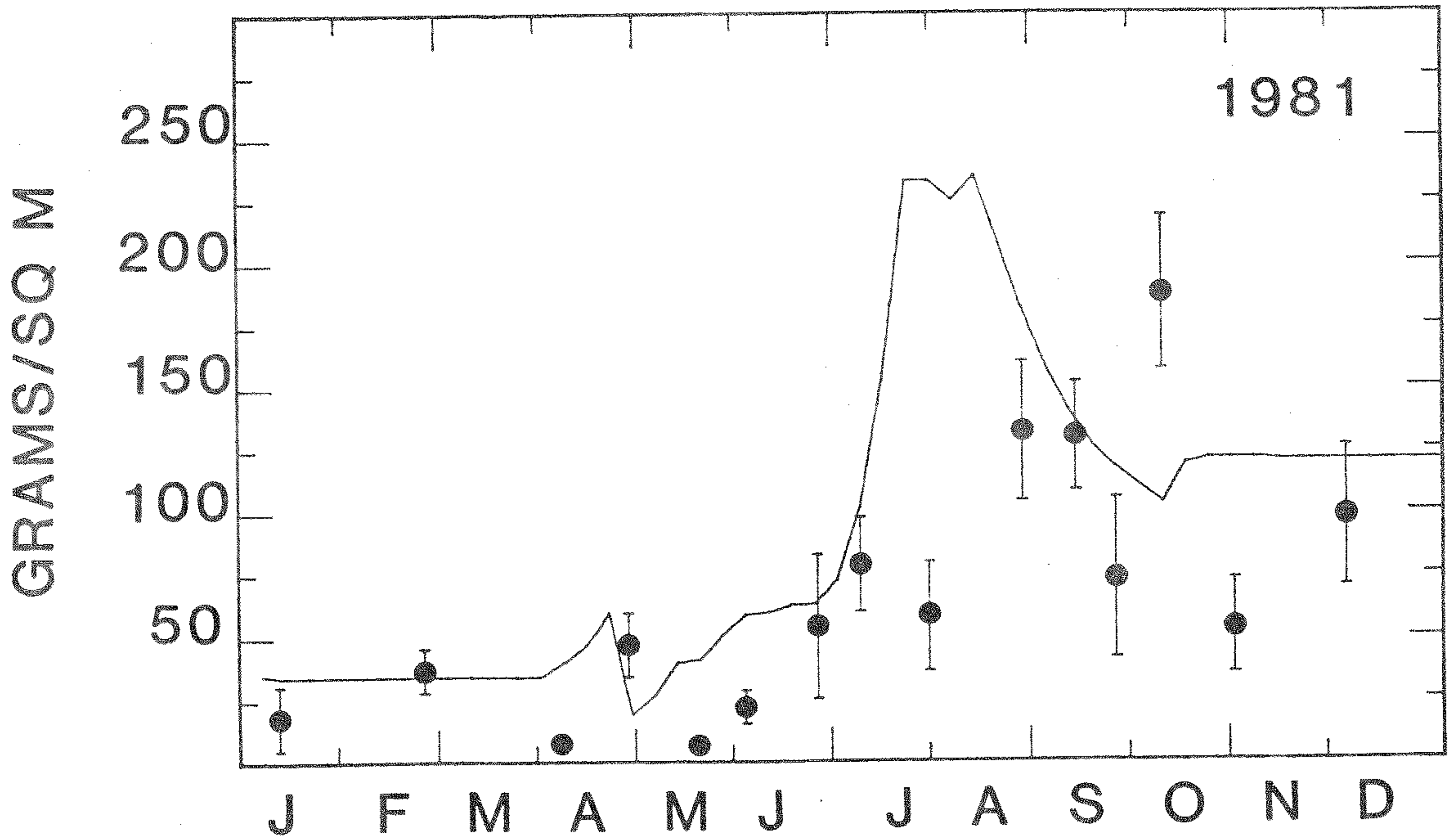

Figure 5. Model estimate (solid line) of <u>Pithophora</u> growth in Surrey Lake for 1981. Solid circles represent measured biomass levels. Error bars are ± 1 SE.

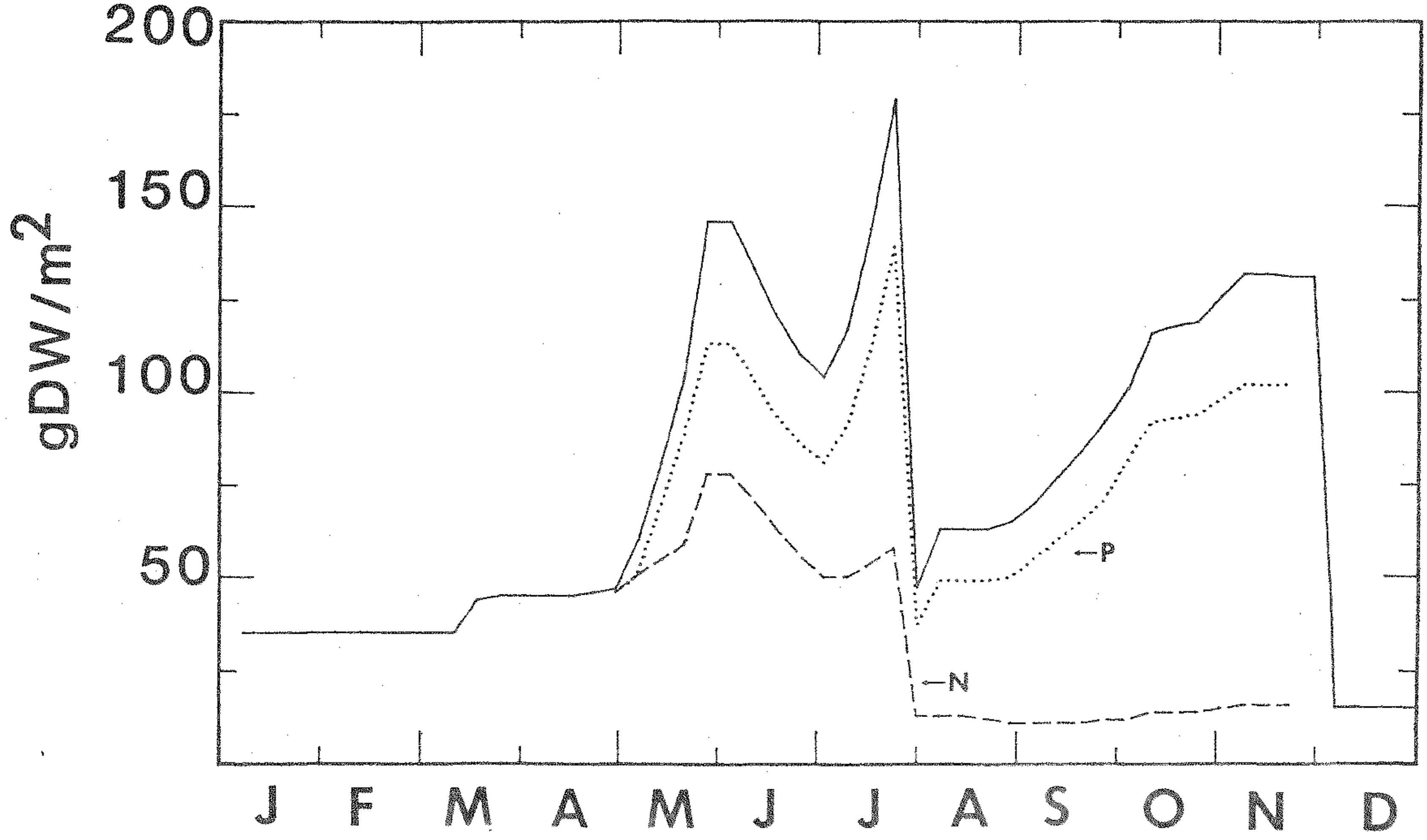

Figure 6. Model estimates for Pithophora growth in Surrey Lake for 1979. Dotted line represents predictions based on a 50% reduction in total phosphorus and dashed line represents predicted biomass for a 50% reduction in nitrate.

1) that all of the agricultural land (699 hectares) in the Surrey Lake watershed was subjected to conventional tillage and fertilized with injected nitrogen during 1979.
2) that runoff was the only source of inorganic nitrogen (NH_3-N plus NO_3-N) into the lake.
3) that the nitrogen loading for the no-till control treatment in the current study approximates the runoff of other land use types (e.g., woodland) in the Surrey Lake watershed during 1979 (approximately 429 hectares in a total watershed of 1128 hectares).

Under these assumptions, the relative input of inorganic nitrogen into Surrey Lake can be estimated for several scenarios. The basic procedure is to calculate the amount of inorganic nitrogen from each of the two land use categories in the watershed assuming that different combinations of tillage system and nitrogen application techniques are applied to the entire area of agricultural land in the watershed.

Table 5 summarizes these calculations using the data from the 25 Jun runoff samples. The column labelled "% of assumed 1979 load" shows the estimated level of inorganic nitrogen for Surrey Lake under the various management systems. Inorganic nitrogen would be reduced by 25 to 49% for the no-till scenarios with the greatest reduction associated with no-till and the use of injected stabilized nitrogen.

Figure 6 shows predictions for Pithophora growth using 1979 Surrey Lake data and also predictions for growth assuming a 50% reduction in nitrogen or phosphorus. This suggests that conversion of the agricultural land in the Surrey Lake watershed to no-till with the use of injected stabilized nitrogen or

TABLE 5. Hypothetical total soluble inorganic nitrogen (TSIN) loading for the Surrey Lake watershed under different combinations of tillage system and nitrogen application method.

Mgmt. System	TSIN yield[1] (kg/ha)	Area (ha)	TSIN for mgmt[2] system (kg)	TSIN load for each scenario (kg)	% of 1979 assumed load
Conv. inj.	0.0918	699.36	64.2	83.8	100
Conv. inj. stabilized	0.1346	699.36	94.1	113.7	136
Conv. surface	0.1620	699.36	113.3	132.9	159
No-till surface	0.0621	699.36	43.4	63.0	75
No-till inj.	0.0366	699.36	25.6	45.2	54
No-till inj. stabilized	0.0335	699.36	23.4	43.0	51
No-till control	0.0458	428.64	19.6	--	--

[1] TSIN = nitrate-N plus ammonia-N

[2] Scenario calculated by adding TSIN for each management system to the no-till control (19.6 kg).

injected nitrogen should lead to a noticeable reduction (approximately 40% of maximum attainable growth in 1979) in *Pithophora* growth. Since there is very little difference between the stabilized or unstabilized nitrogen results, the benefits of stabilizing anhydrous ammonia with nitrapyrin to the crop plant can be realized while still reducing growth of *Pithophora* in the lake. On the other hand, the analysis suggests that use of conventional tillage methods in combination with injected stabilized nitrogen or surface applied nitrogen would probably lead to increased growth of *Pithophora* in Surrey Lake.

POTENTIAL OF COPPER SULFATE TO REDUCE *PITHOPHORA* GROWTH WHEN APPLIED AT SUSCEPTIBLE STAGES IN THE LIFE CYCLE.

Previous studies in this laboratory (O'Neal et al, 1983) suggested that the effect of the algicide copper sulfate in reducing *Pithophora* growth was dependent on the growth stage of the alga. Germinating akinetes (spores) showed the greatest tolerance, akinetes were medium in their response, and vegetative filaments were the most susceptible to copper treatments. Our observations of *Pithophora* in the field clearly showed a seasonality in the appearance of these growth stages. Akinetes are produced in the early fall, overwinter, and germinate in the spring in response to an increase in water temperature. Akinete germination occurs as water temperature increases from 15 to 20 C. Filament growth and mat formation occurs in the summer and is a linear function of increasing water temperatures to at least 26 C.

Although filaments are the most susceptible of the growth stages to copper, the alga is difficult to control. Algicides such as copper sulfate are usually applied in the summer when the mats begin to appear. At a typical dosage of 1 ppm copper sulfate (4 μM Cu^{++}) an 80% reduction of mat material should be expected (Figure 7; see O'Neal et al. 1983 for methods). However, this seldom occurs in the field. Other than a brief browning of the filaments at the surface of the mats, little effect is noted on the alga and recovery is almost immediate (Crance, 1974; Eipper, 1959).

Part of the reason for the lack of activity is probably due to loss of copper ion in alkaline, enriched waters with high concentrations of anions and colloidal particles. However, since sufficient copper usually remains in solution to kill other types of algae, this explanation is not sufficient. Another possibility is related to the morphology of the free-floating mats which, in Pithophora, are extremely dense, tightly woven clumps. This growth form is unlike that of other mat-forming algae in which the mats are looser and appear to contain more interstitial water. Thus, copper applied in the summer to Pithophora mats may not be able to penetrate to the interior of the clump and/or may be absorbed by the outermost filaments so that less copper is available for penetration.

A laboratory experiment was designed to test for copper penetration through Pithophora mats. Mats collected from the field were placed at one end of a vat containing 1.5 l lake water. Copper was introduced in the open liquid at the other end of the vat. One ml of a solution containing 2.25 mg Cu^{++} per ml was used to produce a final concentration of 1.5 mg Cu^{++} per l (approx. 24 μM Cu^{++}) in the vat liquid. Air was bubbled at the introduction point to insure that the copper would move throughout the vat. Liquid samples were removed at distances from the introduction point (0 cm) and analyzed for copper

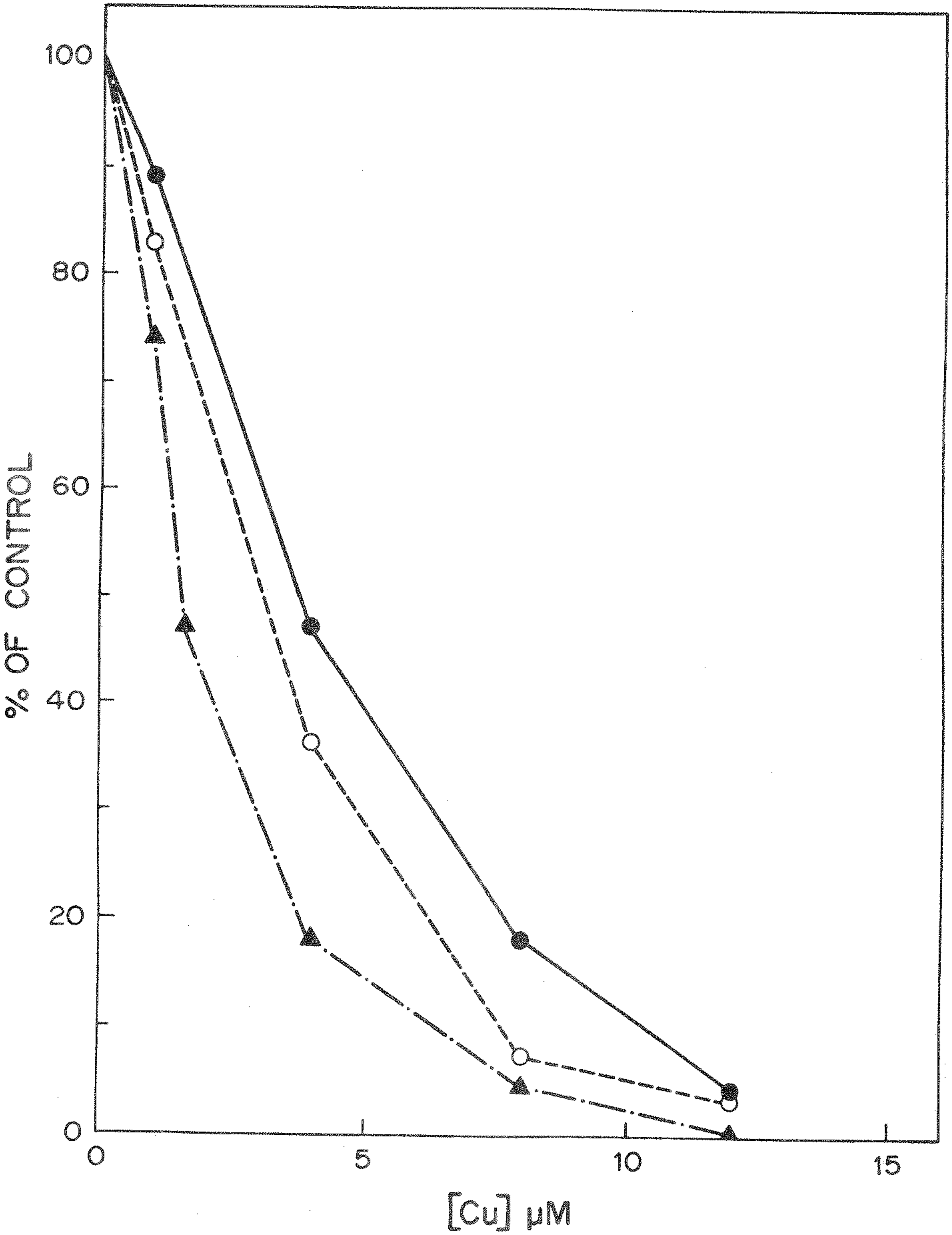

Figure 7. Response of Pithophora filaments (▲), akinetes (o), and germinating akinetes (●) to copper.

removed at distances from the introduction point (0 cm) and analyzed for copper using a colorimetric technique described by St. Grys (1976). As shown in Figure 8, the copper concentration in vats without Pithophora mats remained stable over the 48 hour test period. The copper was evenly dispersed across the vat. In the vats with Pithophora mats, a decrease in movement of the copper 2 cm into the mat was noted 2 hours after copper introduction. Very little copper penetration into the mat was noted at 24 and 48 hours after introduction. In fact, a significant loss of copper throughout the vat, even in the open water portion at 24 and 48 hours suggests that much of the copper may have been taken up by the filaments that it first came in contact with. Mat material at each centimeter interval has been collected and frozen for internal copper analysis.

The results of this experiment support the hypothesis that summer copper treatments are ineffective because of the bulk of vegetation that is present. In contrast to midsummer biomass figures of 150 to 200 g/m2 present in the field, vegetation biomass in winter and early spring can be as low as 10 g/m2. At this stage, the bulk of the vegetation consists primarily of akinetes. Although somewhat more tolerant of copper than the filaments they do appear to be more susceptible as ungerminated than as germinating akinetes (Figure 7). The potential thus exists for effective copper treatments of Pithophora at water temperatures below 15 C (optimum for akinete germination).

The results of a laboratory experiment to test the effect of water temperature on the efficacy of copper on akinetes are illustrated in Figure 9. Three treatments were used: 1) 24 h copper exposure followed by a two week recovery period in copper free medium at 20 C (akinetes were not germinating at the time of copper exposure), 2) copper exposure at 10 C and a two week recovery at 20 C, and 3) copper exposure and a 1 day recovery at 10 C followed by

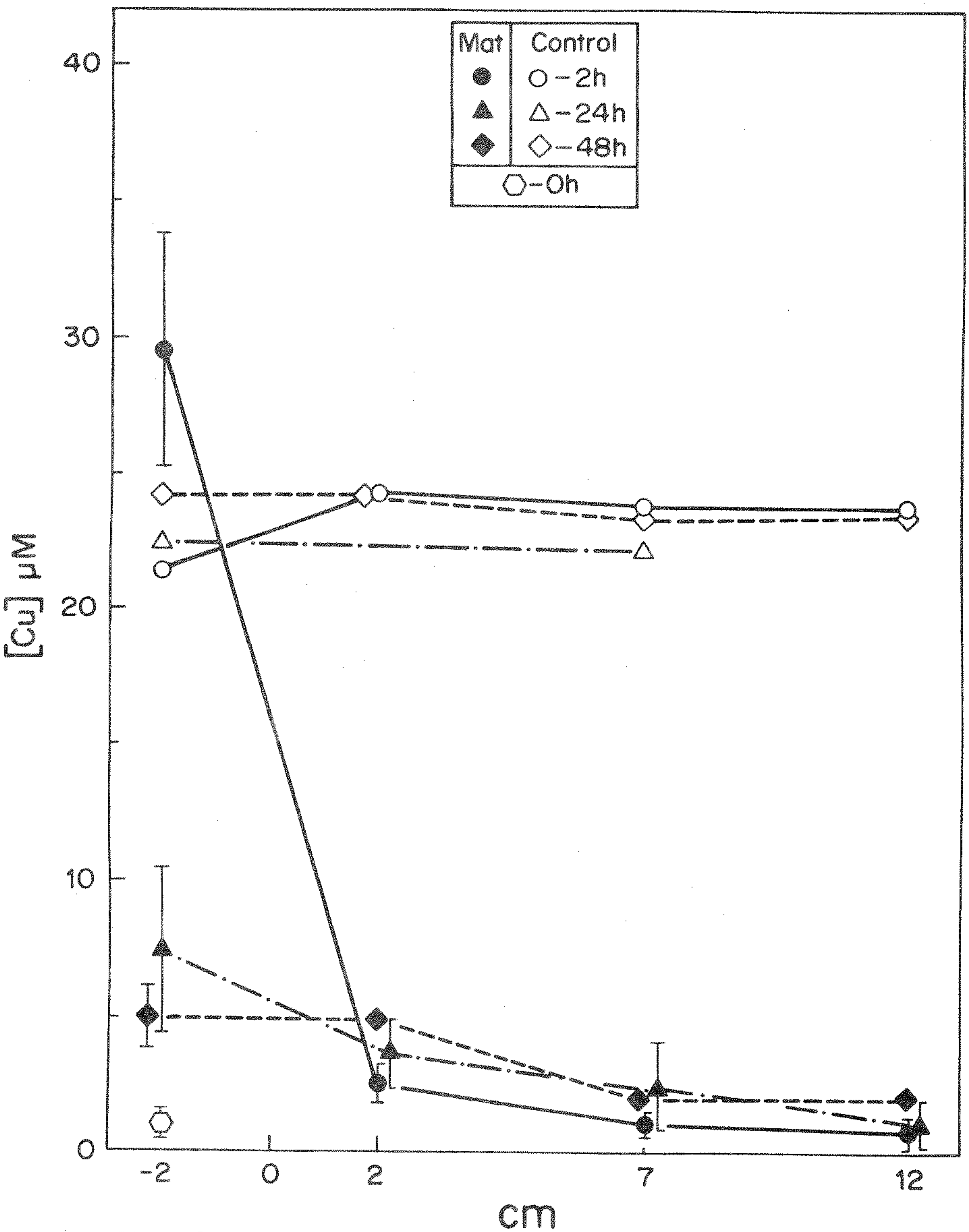

Figure 8. Concentration of copper at various distances within a mat of *Pithophora* filaments. Control contains no mat material.

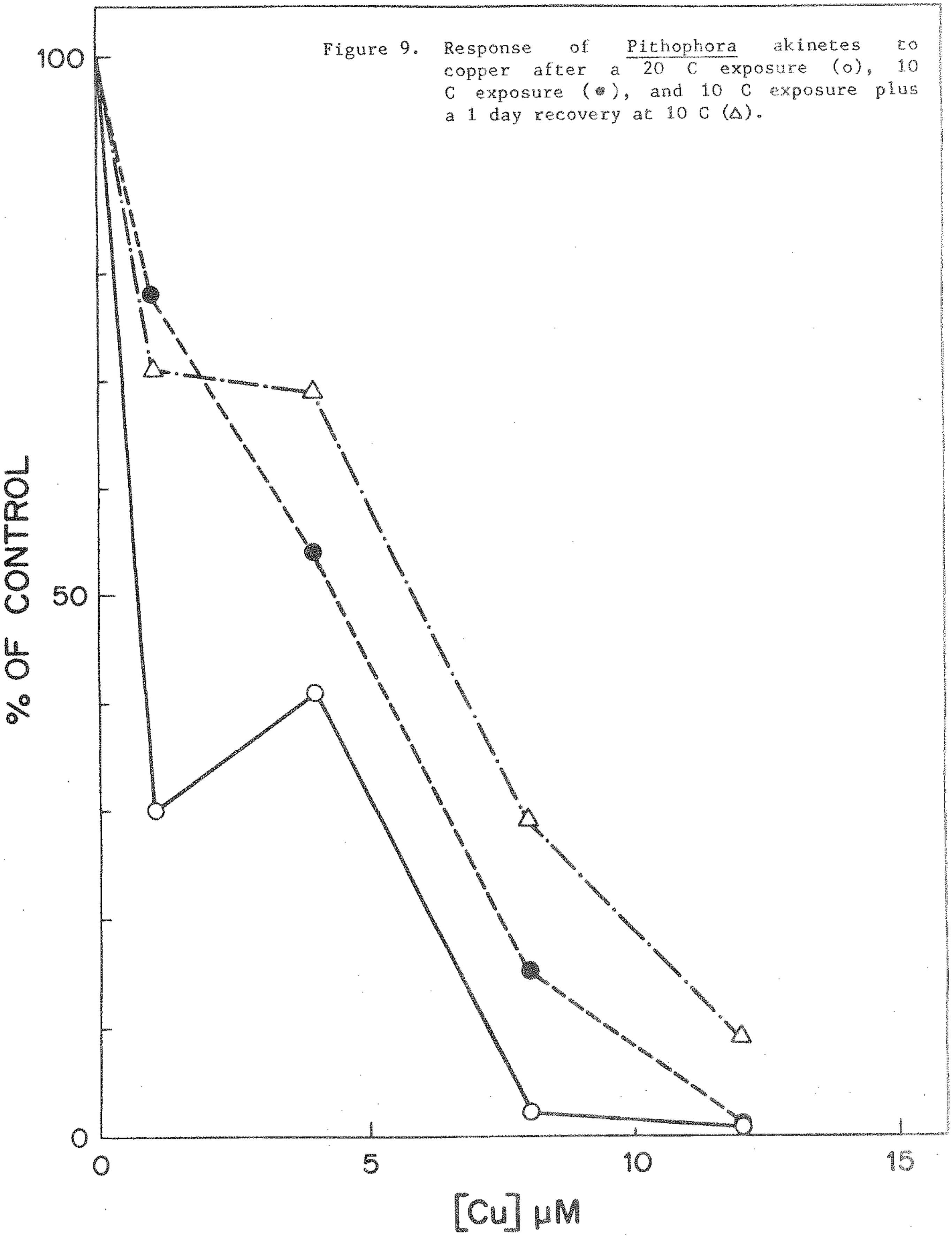

Figure 9. Response of *Pithophora* akinetes to copper after a 20 C exposure (o), 10 C exposure (●), and 10 C exposure plus a 1 day recovery at 10 C (Δ).

recovery at 20 C. The 20 C period is required sometime during the recovery period in order to allow surviving akinetes to germinate and be measured for chlorophyll. Although in general, activity of the copper was reduced at 10 C, the effect appeared to be negated at the higher copper concentrations.

To test the copper susceptibility of Pithophora growth stages under field conditions, arrangements were made to use a pond with a long history of Pithophora infestation at the Grassy Forks Goldfish Hatchery at Martinsville, Indiana. Enclosures, approximately 1.1 m in diameter and 1.3 m long, were constructed of fiberglass sheets bolted together over 1.6 m conduit rod. Conduits were also used to support the fiberglass sheets at 1.6 m intervals. Twelve 1/4" holes in the fiberglass (below the waterline) were drilled and covered with duct tape prior to placement in the pond. The enclosures were placed in the pond at least one week prior to copper treatment to allow suspended sediment to settle. One week following treatment, the tape over the holes was removed to allow free circulation of fresh pond water.

For each treatment time, 6 enclosures were inserted into the pond. Three enclosures were nontreated controls; 3 were treated with copper to achieve a concentration of 1 mg/l (15.8 μM). This high dose was chosen to insure that an effect would be obtained and that differences in responses would be due to treatment time and not to water chemistry or other parameter. Treatment dates and water temperatures were as follows:

24 August, 1983	(28 C)
18 April, 1984	(9 C)
14 May, 1984	(20 C)
11 June, 1984	(32 C)

Figure 10 shows the first set of enclosures at the time of treatment on

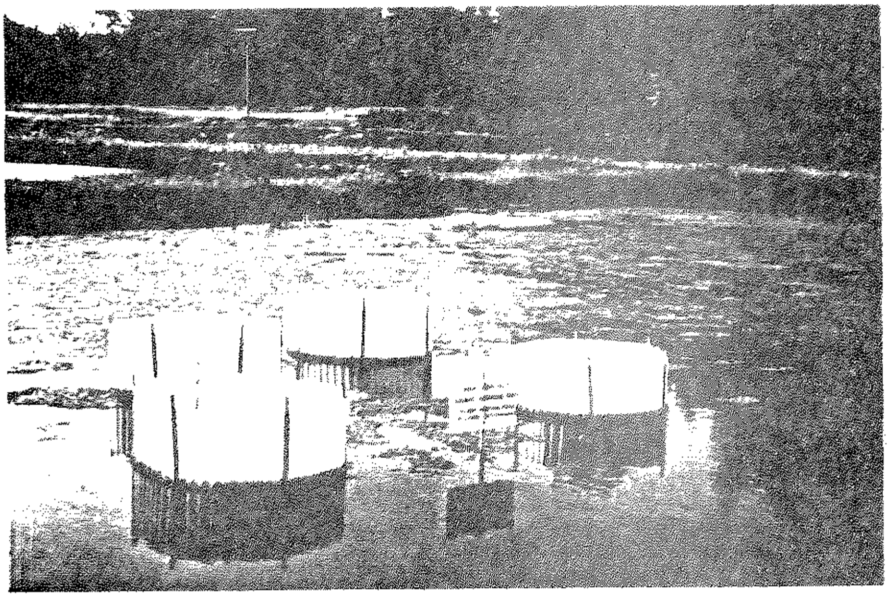

Figure 10. Pithophora - infested pond at Grassy Forks Goldfish Hatchery at the time of the first copper treatment on August 25, 1983.

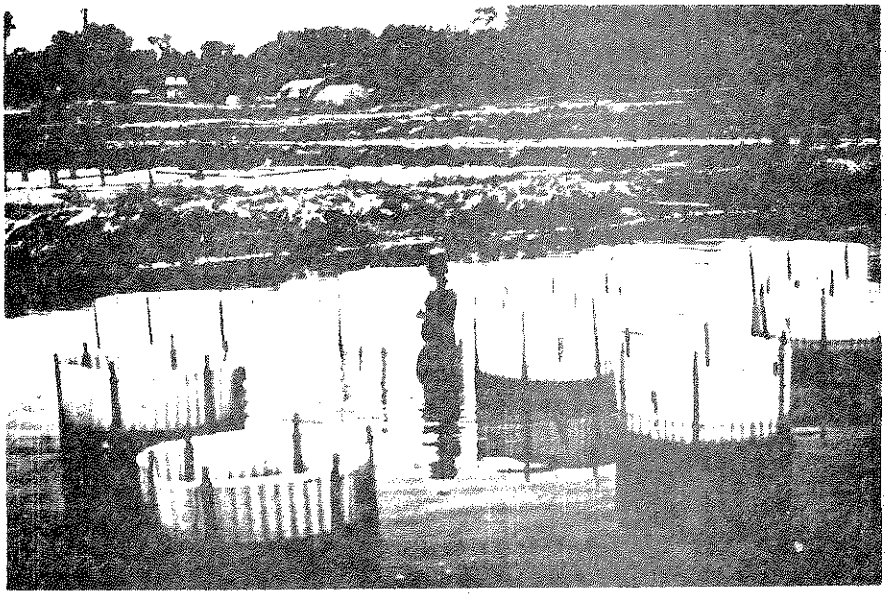

Figure 11. Pithophora - infested pond at Grassy Forks Goldfish Hatchery at the time of copper treatment on April 18, 1984.

August 24. The pond was severely infested with *Pithophora* (floating mats visible between and behind the enclosures); in fact, we were able to insure that each enclosure had approximately an equal amount of *Pithophora* mat prior to treatment. The enclosures survived a heavy ice cover during the winter. On the April 18 treatment date, very little *Pithophora*, either in the form of mats or akinete clumps on the bottom sediments could be detected anywhere in the pond (Figure 11). This unfortunately remained true through the remainder of the treatment times. For unexplained reasons, the *Pithophora* in our test pond disappeared and had not reappeared through October, 1984 when we planned to take efficacy readings. A possible explanation is that the low water level in the pond over the winter (because the hatchery managers dewatered a pond upstream of it for renovation purposes) caused significant *Pithophora* kill. We do not think this is very likely because our previous research has shown *Pithophora* to be relatively tolerant to freezing and thawing. It is unfortunate that this experiment could not be successfully concluded because we believe our experimental set up was a good one and would have yielded valuable information.

It is unlikely that we will repeat this field experiment in the near future, because of the time, effort, and risk involved. We still believe there is potential in early treatment for *Pithophora*, but this may have to be demonstrated using more laboratory experiments rather than relying primarily on field tests.

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                                   SAS

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  2   23MAY84     11.3    conv     cont       2      0.000    0.0000
  3   23MAY84     10.2    conv     cont       3      0.000    0.0000
  4   23MAY84      7.1    conv     cont       4      0.000    0.0000
  5   23MAY84      9.4    conv     cont       5      0.500    1.8600
  6   23MAY84     11.5    conv     cont       6      0.000    0.0000
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                                   SAS

OBS      DATE       SLOPE    TILSYS     NTRT       REP    GAL      RUNOFF

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Appendix A.

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                                    SAS

OBS     DATE      SLOPE    TILSYS    NTRT      REP    GAL      RUNOFF

109    26MAY84     7.3     notil     surfapp    5     0.00     0.0000
110    26MAY84     5.3     notil     surfapp    6     0.00     0.0000
111    26MAY84     8.1     notil     surfapp    7     2.50     9.3000
112    26MAY84     7.1     notil     surfapp    9     6.50    24.1800
113    26MAY84    10.8     notil     inject     1     0.25     0.9300
114    26MAY84     5.8     notil     inject     2     0.00     0.0000
115    26MAY84     7.9     notil     inject     3     1.50     5.5800
116    26MAY84    11.5     notil     inject     4     3.00    11.1600
117    26MAY84     6.0     notil     inject     5     0.12     0.4464
118    26MAY84     6.3     notil     inject     6     0.00     0.0000
119    26MAY84     5.8     notil     inject     7     0.25     0.9300
120    26MAY84    10.2     notil     inject     8     0.00     0.0000
121    26MAY84    13.8     notil     injstb     1     0.00     0.0000
122    26MAY84     8.1     notil     injstb     2     0.00     0.0000
123    26MAY84     7.7     notil     injstb     3     0.00     0.0000
124    26MAY84     9.4     notil     injstb     4     0.00     0.0000
125    26MAY84     6.5     notil     injstb     5     0.00     0.0000
126    26MAY84    10.6     notil     injstb     6     0.12     0.4464
127    26MAY84     6.8     notil     injstb     7     0.25     0.9300
128    26MAY84     8.8     notil     injstb     8     0.00     0.0000
129    30MAY84     7.3     conv      cont       1     0.00     0.0000
130    30MAY84    11.3     conv      cont       2     0.00     0.0000
131    30MAY84    10.2     conv      cont       3     0.00     0.0000
132    30MAY84     7.1     conv      cont       4     0.00     0.0000
133    30MAY84     9.4     conv      cont       5     0.25     0.9300
134    30MAY84    11.5     conv      cont       6     0.75     2.7900
135    30MAY84     5.6     conv      cont       7     0.25     0.9300
136    30MAY84     5.2     conv      cont       8     0.00     0.0000
137    30MAY84     7.5     conv      surfapp    1     0.00     0.0000
138    30MAY84    13.5     conv      surfapp    2     0.00     0.0000
139    30MAY84     9.4     conv      surfapp    3     0.00     0.0000
140    30MAY84     7.3     conv      surfapp    4     0.00     0.0000
141    30MAY84     7.1     conv      surfapp    5     0.00     0.0000
142    30MAY84    11.7     conv      surfapp    6     1.00     3.7200
143    30MAY84     5.6     conv      surfapp    7     0.00     0.0000
144    30MAY84     4.6     conv      surfapp    8     0.00     0.0000
145    30MAY84     7.5     conv      inject     1     0.00     0.0000
146    30MAY84    10.4     conv      inject     2     0.00     0.0000
147    30MAY84     6.7     conv      inject     3     0.00     0.0000
148    30MAY84     6.3     conv      inject     4     0.25     0.9300
149    30MAY84     8.1     conv      inject     5     0.75     2.7900
150    30MAY84     8.3     conv      inject     6     0.25     0.9300
151    30MAY84     7.5     conv      inject     7     0.75     2.7900
152    30MAY84     8.3     conv      inject     8     0.00     0.0000
153    30MAY84     9.0     conv      injstb     1     0.00     0.0000
154    30MAY84     9.8     conv      injstb     2     0.00     0.0000
155    30MAY84    10.8     conv      injstb     3     0.00     0.0000
156    30MAY84     6.7     conv      injstb     4     0.00     0.0000
157    30MAY84     8.1     conv      injstb     5     0.00     0.0000
158    30MAY84     5.8     conv      injstb     6     0.75     2.7900
159    30MAY84     6.3     conv      injstb     7     0.00     0.0000
160    30MAY84     6.9     conv      injstb     8     1.75     6.5100
161    30MAY84     9.8     notil     cont       1     0.00     0.0000
162    30MAY84     9.4     notil     cont       2     0.00     0.0000
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Appendix A.

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                                  SAS

OBS    DATE     SLOPE   TILSYS   NTRT      REP     GAL      RUNOFF

163   30MAY84     6.8   notil    cont       3      0.00      0.00
164   30MAY84     6.5   notil    cont       4      0.25      0.93
165   30MAY84     9.0   notil    cont       5      0.00      0.00
166   30MAY84     7.9   notil    cont       6      0.25      0.93
167   30MAY84     9.2   notil    cont       7      0.25      0.93
168   30MAY84     9.6   notil    cont       8      1.00      3.72
169   30MAY84    10.2   notil    surfapp    1      0.75      2.79
170   30MAY84    10.2   notil    surfapp    2      3.50     13.02
171   30MAY84     9.4   notil    surfapp    3      0.00      0.00
172   30MAY84    13.1   notil    surfapp    4      1.00      3.72
173   30MAY84     7.3   notil    surfapp    5      0.50      1.86
174   30MAY84     6.3   notil    surfapp    6      0.00      0.00
175   30MAY84     8.1   notil    surfapp    7      1.25      4.65
176   30MAY84     7.1   notil    surfapp    9     10.50     39.06
177   30MAY84    10.8   notil    inject     1      0.50      1.86
178   30MAY84     5.8   notil    inject     2      0.00      0.00
179   30MAY84     7.9   notil    inject     3      1.25      4.65
180   30MAY84    11.5   notil    inject     4      3.75     13.95
181   30MAY84     6.0   notil    inject     5      0.25      0.93
182   30MAY84     6.3   notil    inject     6      0.50      1.86
183   30MAY84     5.8   notil    inject     7      0.25      0.93
184   30MAY84    10.2   notil    inject     8      0.25      0.93
185   30MAY84    13.8   notil    injstb     1      1.00      3.72
186   30MAY84     8.1   notil    injstb     2      0.00      0.00
187   30MAY84     7.7   notil    injstb     3      0.00      0.00
188   30MAY84     9.4   notil    injstb     4      0.00      0.00
189   30MAY84     6.5   notil    injstb     5      0.00      0.00
190   30MAY84    10.6   notil    injstb     6      0.50      1.86
191   30MAY84     8.8   notil    injstb     7      0.25      0.93
192   30MAY84     8.8   notil    injstb     8      0.00      0.00
193   25JUN84     7.3   conv     cont       1      8.75     32.55
194   25JUN84    11.3   conv     cont       2     11.00     40.92
195   25JUN84    10.2   conv     cont       3     15.25     56.73
196   25JUN84     7.1   conv     cont       4      3.00     11.16
197   25JUN84     9.4   conv     cont       5     13.50     50.22
198   25JUN84    11.5   conv     cont       6      5.25     19.53
199   25JUN84     5.6   conv     cont       7      2.25      8.37
200   25JUN84     5.2   conv     cont       8      5.50     20.46
201   25JUN84     7.5   conv     surfapp    1     11.00     40.92
202   25JUN84    13.5   conv     surfapp    2     12.00     44.64
203   25JUN84     9.4   conv     surfapp    3      7.00     26.04
204   25JUN84     7.3   conv     surfapp    4     10.00     37.20
205   25JUN84     7.1   conv     surfapp    5      2.00      7.44
206   25JUN84    11.7   conv     surfapp    6      7.00     26.04
207   25JUN84     5.6   conv     surfapp    7      3.50     13.02
208   25JUN84     4.6   conv     surfapp    8      7.00     26.04
209   25JUN84     7.5   conv     inject     1     32.00    119.04
210   25JUN84    10.4   conv     inject     2      5.00     18.60
211   25JUN84     6.7   conv     inject     3      7.00     26.04
212   25JUN84     6.3   conv     inject     4      5.00     18.60
213   25JUN84     8.1   conv     inject     5      7.00     26.04
214   25JUN84     8.3   conv     inject     6      3.00     11.16
215   25JUN84     7.5   conv     inject     7     10.00     37.20
216   25JUN84     8.3   conv     inject     8      0.00      0.00
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Appendix A.

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                                   SAS

 OBS      DATE       SLOPE    TILSYS    NTRT      REP     GAL     RUNOFF

 217     25JUN84      9.0     conv      injstb     1     26.25     97.65
 218     25JUN84      9.8     conv      injstb     2      5.00     18.60
 219     25JUN84     10.8     conv      injstb     3     10.00     37.20
 220     25JUN84      6.7     conv      injstb     4      4.00     14.88
 221     25JUN84      8.1     conv      injstb     5      4.00     14.88
 222     25JUN84      5.8     conv      injstb     6      3.25     12.09
 223     25JUN84      6.3     conv      injstb     7      2.50      9.30
 224     25JUN84      6.9     conv      injstb     8      3.25     12.09
 225     25JUN84      9.8     notil     cont       1      4.50     16.74
 226     25JUN84      9.4     notil     cont       2      0.00      0.00
 227     25JUN84      8.8     notil     cont       3      4.00     14.88
 228     25JUN84      6.5     notil     cont       4      4.00     14.88
 229     25JUN84      9.0     notil     cont       5      7.25     26.97
 230     25JUN84      7.9     notil     cont       6      1.00      3.72
 231     25JUN84      9.2     notil     cont       7      2.25      8.37
 232     25JUN84      9.6     notil     cont       8      4.00     14.88
 233     25JUN84     10.2     notil     surfapp    1      0.00      0.00
 234     25JUN84     10.2     notil     surfapp    2      3.00     11.16
 235     25JUN84      9.4     notil     surfapp    3      4.00     14.88
 236     25JUN84     13.1     notil     surfapp    4      3.50     13.02
 237     25JUN84      7.3     notil     surfapp    5      5.00     18.60
 238     25JUN84      6.3     notil     surfapp    6      0.00      0.00
 239     25JUN84      8.1     notil     surfapp    7      1.00      3.72
 240     25JUN84      7.1     notil     surfapp    9      6.50     24.18
 241     25JUN84     10.8     notil     inject     1      5.00     18.60
 242     25JUN84      5.8     notil     inject     2      1.50      5.58
 243     25JUN84      7.9     notil     inject     3     10.00     37.20
 244     25JUN84     11.5     notil     inject     4      5.75     21.39
 245     25JUN84      6.0     notil     inject     5      4.50     16.74
 246     25JUN84      6.3     notil     inject     6      1.50      5.58
 247     25JUN84      5.8     notil     inject     7      1.75      6.51
 248     25JUN84     10.2     notil     inject     8      0.50      1.86
 249     25JUN84     13.8     notil     injstb     1      7.00     26.04
 250     25JUN84      8.1     notil     injstb     2      0.00      0.00
 251     25JUN84      7.7     notil     injstb     3      3.50     13.02
 252     25JUN84      9.4     notil     injstb     4      3.00     11.16
 253     25JUN84      6.5     notil     injstb     5      2.00      7.44
 254     25JUN84     10.6     notil     injstb     6      2.00      7.44
 255     25JUN84      3.8     notil     injstb     7      1.00      3.72
 256     25JUN84      8.8     notil     injstb     8      0.00      0.00
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Nutrient analysis for tillage system vs. nitrogen application method study

Appendix B. May 23, 1984

OBS	TILSYS	NTRT	REP	NH3	NO2	NO3	TNF	TNUF	TPF	TPUF	SRP	FILTSD
1	conv	cont	5	13.19	0.03	0.00	52.29	64.30	0.00	1.88	0.00	110.86
2	conv	cont	7	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	90.48
3	conv	cont	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.68
4	conv	surapp	7	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	47.34
5	conv	inject	4	0.31	0.00	0.00	0.00	9.64	0.00	2.08	0.00	110.79
6	conv	inject	5	12.30	0.39	0.00	140.69	213.46	0.00	5.06	0.00	139.81
7	conv	inject	8	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	107.57
8	conv	injstb	2	0.00	0.00	0.00	104.07	182.17	0.00	0.00	0.00	52.16
9	conv	injstb	6	0.00	0.03	0.00	35.58	115.06	0.00	0.00	0.00	37.98
10	conv	injstb	8	22.78	0.42	57.59	152.26	0.00	0.00	2.48	0.00	149.38
11	notil	cont	3	0.00	0.27	0.00	60.04	134.62	0.00	0.00	0.00	42.95
12	notil	cont	5	0.00	0.00	0.00	82.64	115.26	0.00	0.00	0.00	65.43
13	notil	cont	7	15.15	0.29	0.00	44.93	115.93	0.00	1.15	0.00	97.88
14	notil	cont	8	2.71	0.02	6.59	133.05	15.84	0.00	0.12	0.00	133.85
15	notil	surapp	2	611.31	1.09	3175.32	559.10	566.18	0.00	0.59	0.00	143.12
16	notil	surapp	3	115.81	1.67	734.69	221.63	233.98	4.32	5.71	2.63	37.84
17	notil	surapp	4	35.96	0.00	4.53	0.00	13.41	0.00	5.21	0.00	76.58
18	notil	surapp	7	467.04	5.23	1169.02	335.66	435.94	0.12	6.31	0.00	44.57
19	notil	surapp	8	725.24	7.43	39.26	1060.56	571.08	1.05	3.91	0.71	24.15
20	notil	inject	1	9.06	0.00	25.58	0.00	15.76	0.00	8.69	0.00	50.71
21	notil	inject	3	312.96	7.48	202.62	482.67	578.15	0.33	2.65	0.00	57.36
22	notil	inject	4	675.26	8.34	271.56	600.64	493.52	7.69	14.05	0.71	82.71
23	notil	inject	5	61.50	0.68	17.77	179.54	264.16	0.00	7.51	0.00	90.03
24	notil	inject	7	11.39	0.26	0.00	46.52	132.24	0.00	2.10	0.00	60.06
25	notil	injstb	1	362.82	3.41	147.13	363.06	86.47	3.36	5.51	0.19	36.66
26	notil	injstb	3	23.75	0.00	86.01	0.00	0.00	0.00	0.00	0.00	35.44
27	notil	injstb	6	8.21	0.00	0.00	127.90	120.71	0.00	3.03	0.00	20.23
28	notil	injstb	7	3.17	0.00	0.00	102.67	197.44	0.00	0.38	0.00	47.35

Nutrient analysis for tillage system vs.
nitrogen application method study

Appendix B. May 30, 1984

OBS	TILSYS	NTRT	REP	NH3	NO2	NO3	TNF	TNUF	TPF	TPUF	SRP	FILTSD
1	conv	cont	5	1.64	0.022	2.64	0.072	6.74	1.07	0.12	0.00	14.4900
2	conv	cont	6	0.00	0.004	0.93	3.540	0.00	0.00	0.13	0.00	8.1200
3	conv	cont	7	0.00	0.059	1.82	10.950	11.62	0.00	0.00	0.00	11.5700
4	conv	surapp	6	10.38	0.026	15.30	10.500	5.18	0.00	0.47	0.00	8.8100
5	conv	inject	4	0.00	0.000	3.03	10.870	10.53	0.00	0.00	0.00	5.1300
6	conv	inject	5	3.29	0.130	5.60	6.610	7.09	0.00	0.42	0.00	27.4600
7	conv	inject	6	0.00	0.000	1.14	6.360	5.74	0.00	0.00	0.00	13.1500
8	conv	inject	7	0.00	0.110	2.95	30.350	11.02	0.00	0.07	0.00	32.4300
9	conv	injstb	6	0.00	0.000	2.35	0.000	0.00	0.00	0.28	0.00	18.1900
10	conv	injstb	8	23.94	0.170	79.74	23.950	25.33	0.00	0.22	0.00	17.5600
11	notil	cont	4	0.00	0.000	5.51	13.030	12.74	0.00	0.04	0.00	24.4700
12	notil	cont	6	0.00	0.000	0.00	25.880	0.00	0.62	0.84	0.75	4.8700
13	notil	cont	7	0.03	0.000	4.41	42.950	11.96	0.00	0.03	0.00	8.8000
14	notil	cont	8	0.00	0.030	38.89	13.950	11.87	0.00	0.00	0.00	6.6400
15	notil	surapp	1	4.99	0.000	34.46	1.810	0.00	0.00	0.21	0.00	18.8000
16	notil	surapp	2	218.96	0.120	1092.83	30.750	146.94	0.13	1.92	0.49	20.9500
17	notil	surapp	4	0.00	0.060	4.64	14.520	15.85	0.00	0.11	0.00	15.1200
18	notil	surapp	5	0.51	0.020	2.46	3.720	12.10	0.00	0.00	0.00	11.0100
19	notil	surapp	7	37.95	0.470	135.56	20.660	19.45	0.00	0.59	0.00	0.0000
20	notil	surapp	8	336.13	8.740	3573.63	367.180	138.31	0.00	0.24	0.00	12.3200
21	notil	inject	1	0.08	0.000	12.02	14.160	0.00	0.00	0.18	0.00	12.7600
22	notil	inject	3	22.02	2.870	86.22	29.170	3.96	0.00	0.38	0.55	31.9500
23	notil	inject	4	73.81	8.010	145.55	221.650	69.38	0.19	1.62	0.08	26.6900
24	notil	inject	5	0.61	0.350	4.54	0.000	0.00	0.00	0.21	0.00	3.5100
25	notil	inject	6	0.00	0.060	0.00	73.700	14.33	0.00	0.06	0.00	2.1600
26	notil	inject	7	0.00	0.070	0.00	19.970	5.84	0.00	0.00	0.00	4.4800
27	notil	inject	8	0.00	0.000	0.33	0.000	0.00	0.00	0.12	0.00	2.1000
28	notil	injstb	1	16.37	0.370	21.15	0.000	5.78	0.00	1.31	0.00	9.0300
29	notil	injstb	6	11.71	0.200	2.89	10.670	1.84	0.00	0.54	0.00	0.0000
30	notil	injstb	7	0.00	0.090	0.14	17.810	4.75	0.00	0.00	0.00	.

Nutrient analysis for tillage system vs.
nitrogen application methoc study
June 25, 1984

Appendix B.

OBS	TILSYS	NTRT	REP	NH3	NC2	NO3	TNF	TNUF	TPF	TPUF	SRP	FILTSD
1	conv	cont	1	11.72	0.26	0.00	8.52	16.67	0.00	2.43	0.00	144.03
2	conv	cont	2	0.00	0.69	0.00	0.00	0.00	0.00	0.14	0.03	64.43
3	conv	cont	3	0.00	0.11	13.04	32.74	36.71	0.00	0.24	0.00	113.07
4	conv	cont	5	49.10	0.00	109.93	22.83	8.69	0.00	0.97	0.00	113.70
5	conv	cont	6	23.15	0.00	30.52	0.00	27.39	4.18	29.67	2.92	196.08
6	conv	cont	7	14.25	1.03	17.64	53.04	32.51	0.06	0.49	0.27	146.56
7	conv	cont	8	16.47	0.00	36.33	0.00	3.55	0.00	11.24	0.00	116.81
8	conv	surapp	1	189.58	0.41	89.57	194.14	158.59	0.00	2.59	0.03	231.42
9	conv	surapp	2	79.20	0.46	105.08	105.50	129.76	0.03	2.14	0.00	256.06
10	conv	surapp	3	56.86	1.75	105.79	67.07	19.45	0.99	1.82	0.00	120.21
11	conv	surapp	4	16.52	0.00	76.14	0.00	40.36	0.00	0.59	0.00	198.56
12	conv	surapp	5	47.56	0.00	33.11	0.00	0.00	0.00	0.00	0.00	129.04
13	conv	surapp	6	95.92	0.00	65.21	28.16	65.32	0.83	35.10	0.00	139.94
14	conv	surapp	7	49.99	0.09	49.41	52.96	78.12	0.00	1.34	0.00	188.53
15	conv	surapp	8	47.17	0.00	97.08	14.31	66.38	0.00	21.57	0.00	157.08
16	conv	inject	1	24.15	0.27	69.17	116.55	91.99	5.31	7.56	4.95	131.49
17	conv	inject	2	48.05	0.78	32.79	245.82	257.98	0.06	0.54	0.04	15.48
18	conv	inject	3	10.15	0.53	58.47	0.00	0.00	0.00	0.66	0.00	146.21
19	conv	inject	4	32.55	0.12	78.76	0.00	0.00	0.00	21.70	0.02	208.88
20	conv	inject	6	4.84	0.00	32.96	0.00	0.00	0.00	0.00	0.00	161.44
21	conv	inject	7	31.29	0.66	88.58	91.83	93.17	0.02	3.98	0.08	450.95
22	conv	injstb	1	193.42	0.00	229.11	148.06	231.00	1.94	39.69	0.00	273.04
23	conv	injstb	2	101.70	0.00	41.97	17.75	111.85	2.55	25.93	1.51	115.04
24	conv	injstb	3	0.00	1.34	25.16	0.00	10.61	0.15	0.05	0.00	151.32
25	conv	injstb	5	35.34	0.00	38.90	0.00	0.00	0.17	1.94	0.00	210.99
26	conv	injstb	6	15.04	0.00	35.16	0.00	0.00	0.60	0.65	0.79	91.34
27	conv	injstb	7	36.67	0.49	46.58	50.59	61.87	0.00	1.00	0.29	252.57
28	conv	injstb	8	38.90	0.00	37.37	0.00	2.59	1.32	15.23	0.00	102.50
29	notil	cont	1	15.86	0.13	0.00	0.00	0.00	1.82	1.74	0.99	16.67
30	notil	cont	3	2.44	0.05	0.00	0.00	0.00	0.00	0.00	0.00	69.97
31	notil	cont	4	32.20	0.00	55.16	0.00	0.00	0.00	8.34	0.00	61.48
32	notil	cont	5	45.76	0.04	47.97	84.72	81.48	0.00	0.29	0.00	109.90
33	notil	cont	6	0.00	0.00	13.39	0.00	0.00	0.00	6.99	0.00	30.50
34	notil	cont	7	22.15	0.35	14.00	22.69	77.45	2.59	3.62	2.80	95.15
35	notil	cont	8	17.48	0.00	30.71	0.00	0.00	0.00	9.20	0.00	144.74
36	notil	surapp	2	29.45	0.11	49.08	81.28	90.24	0.00	2.18	0.32	21.91
37	notil	surapp	3	17.68	0.01	31.03	56.17	80.35	0.00	0.26	0.00	57.87
38	notil	surapp	4	7.39	0.07	22.76	0.00	0.00	0.00	29.22	0.28	55.78
39	notil	surapp	7	54.02	0.89	10.77	36.58	85.31	0.66	3.35	0.27	102.63
40	notil	surapp	8	28.75	0.05	37.49	40.55	72.73	0.00	2.57	0.04	378.32
41	notil	inject	1	0.18	0.18	0.00	0.00	0.00	0.00	0.00	0.00	85.39
42	notil	inject	2	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	38.99
43	notil	inject	3	15.71	0.00	31.01	0.00	0.00	0.39	0.82	0.00	92.51
44	notil	inject	4	55.65	0.14	45.91	0.00	0.00	0.86	38.85	1.56	35.43
45	notil	inject	5	3.78	0.16	23.95	0.00	0.00	1.37	8.67	2.39	20.96
46	notil	inject	6	0.00	0.09	0.00	0.00	0.00	0.99	1.09	1.08	9.56
47	notil	inject	7	31.88	0.04	4.69	24.61	36.42	0.45	0.00	0.00	104.63
48	notil	inject	8	0.00	0.00	9.44	0.00	0.00	4.22	6.50	3.28	21.45
49	notil	injstb	1	15.68	0.57	0.00	4.31	45.34	7.63	9.92	8.14	48.48
50	notil	injstb	2	5.96	0.12	0.00	0.00	0.00	0.76	0.49	0.46	37.23
51	notil	injstb	3	23.76	0.43	32.12	1.20	18.14	0.59	0.00	0.79	36.01
52	notil	injstb	4	42.60	0.33	19.45	0.00	33.52	0.39	27.87	0.00	33.64

Appendix B.

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           Nutrient analysis for tillage system vs.
                nitrogen application method study
                          June 25, 1984

OBS TILSYS   NTRT   REP   NH3   NO2    NO3  TNF   TNUF TPF TPUF   SRP  FILTSD

53  notil   injstb   6  22.51 0.14 17.49   0    0.00  0  31.14 0.00 50.60
54  notil   injstb   7   0.00 0.00  6.95   0   38.67  0   0.02 0.05 74.52
```