APPENDIX I

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EVALUATION OF RICE WATER MANAGEMENT PRACTICES ON MOLINATE DISSIPATION AND DISCHARGE, RICE PESTS AND RICE PRODUCTION

Steven C. Scardaci[1], James E. Hill[2], Donald G. Crosby[3],
Albert A. Grigarick[4], Robert K. Webster[5], and Robert K. Washino[4]

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[1] University of California Farm Advisor, Colusa County, [2] Agronomist, Agronomy Extension, [3] Professors, Departments of Environmental Toxicology, [4] Entomology, [5] Plant Pathology, respectively, University of California, Davis.

Contributors:

PLANNING AND DESIGN:	Steven C. Scardaci, University of California Cooperative Extension, Colusa County; James E. Hill, Dept. of Agronomy and Range Science Extension, U.C. Davis; Donald G. Crosby, Dept. of Environmental Toxicology, U.C. Davis; David E. Bayer, Dept. of Botany, U.C. Davis.
FIELD MANAGEMENT:	Steven C. Scardaci, University of California Cooperative Extension, Colusa County; George Tibbitts and Blake Covert, Dept. of Agronomy and Range Science Extension, U.C. Davis.
MOLINATE MONITORING:	Donald G. Crosby, Richard M. Higashi, Rita Look and Richard B. Draper, Jr, Dept. of Environmental Toxicology, U.C. Davis.
RICE AND WEED MONITORING:	Steven C. Scardaci, University of California Cooperative Extension, Colusa County; James E. Hill, George Tibbitts and Blake Covert, Dept. of Agronomy and Range Science Extension, U.C. Davis.
DISEASE MONITORING:	Robert K. Webster and Pamela S. Gunnell, Dept. of Plant Pathology, U.C. Davis.
INVERTEBRATE MONITORING:	Albert A. Grigarick, Joseph Lynch, Mike Oraze and Kirk Smith, Dept. of Entomology, U.C. Davis.
MOSQUITO MONITORING:	Robert K. Washino and Susan Palchick, Dept. of Entomology, U.C. Davis.
DATA ANALYSIS:	Gail Nishimoto, Chris Weber-Johnson and George Tibbitts, Dept. of Agronomy and Range Science Extension, U.C. Davis and Carol Adams, Biometrical Services, U.C. Riverside.
REPORT PREPARATION:	Carol Genera and Liz Morse, University of California Cooperative Extension, Colusa County; Kay Williams, Dept. of Agronomy and Range Science Extension, U.C. Davis.

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DISCLAIMER

Mention and use of products in this study is in no way intended to be an endorsement of products, nor is criticism implied of similar products which are not mentioned.

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SUMMARY

A field trial was established in Colusa County in 1984 and 1985 to study the effect of rice water management practices on molinate dissipation and discharge and on rice pests and production. The water management treatments used in this study were designed to determine the effect of water depth, continuous vs. discontinuous flooding (drainage) and water holding period on the above factors.

In 1985, general molinate monitoring of rice field water following a postflood application showed that the half-life averaged between 3.5 and 4.1 days over all treatments. Dissipation rates between treatments were not substantially different over the 32 day monitoring period. Water released or drained from plots following an 8-day water holding period (WHP) had molinate residues ranging from 533 to 713 ppb; following a 16-day WHP, they ranged from 52 to 173 ppb; and following a 32-day WHP, they ranged from 5 to 12 ppb. Our 1984 results were similar though somewhat lower. In 1984, the calculated half-life for molinate ranged from 2.8 to 3.8 days and concentrations were correspondingly lower as well. These differences are probably due to greater volatization losses caused by high winds in 1984. The net discharge of molinate decreased as the WHP increased from 8 to 32 days. Also, for a given WHP (i.e. 8 days) net discharge decreased as the amount of water released decreased. Therefore, complete drainage after the 8 day WHP resulted in a high net discharge while resumption of a normal spill after a 32 day WHP resulted in a low one. Intensive herbicide monitoring showed that residue concentrations fluctuate substantially over a matter of hours (>1 ppm/3 hours). These variations make intensive monitoring important in establishing accurate dissipation curves.

Molinate residue levels following a preflood application were substantially lower than those following a postflood application. In fact, the 3 day residue levels following the preflood application were comparable to the 16 day levels following the postflood application. These results are very similar to our 1984 results and merit further study.

In 1985, water depth and drainage had significant effects on weed growth. These effects varied somewhat by species. In general, broadleaf weeds were favored by shallow water, while deep water adversely affected their growth. This is evident from the poorer weed control ratings in shallow water. Drainage temporarily inhibited the growth of Ducksalad, Arrowhead and Waterhyssop but stimulated Smallflower Umbrellaplant. These results are similar to those observed in 1984 with the exception that weed growth was not affected by the longer WHP. Grassy weeds were not prevalent enough to make growth measurements. Control of Watergrass, Ducksalad and Waterhyssop was poorest in plots drained for 10 days. Since invertebrate populations were low and damage to rice were minimal in 1984 no invertebrate pest monitoring was conducted in 1985. Stem Rot and Aggregate Sheath Spot, two diseases of rice, were at such low levels that they were not a factor in 1985. In 1984 however, Aggregate Sheath Spot was less severe in plots drained for 10 days after the WHP compared to those continuously flooded. Mosquito larval (Culex tarsalis) development was fastest in deep drain and deep water treatments and slowest in shallow water. This was similar to our

1984 results.

Rice seedling growth was most rapid in shallow water and slowest in deep water. Growth of seedlings was adversely affected when water was drained for 10 days after the WHP. Heading and maturity were delayed by shallow water. A moderate water depth resulted in the highest yield while the shallow water and drainage treatments resulted in the lowest yields. Moderate water appeared to provide a favorable environment for rice growth while at the same time it helped suppress weed growth. Water holding period had no effect on rice growth and yield. Fortunately we did not experience any production problems (i.e. algae, salinity, toxic gases and acids, or rice water weevil) that could have precluded us from holding water for long periods or that could have caused adverse effects on the crop. Although our 1984 results indicated that long WHPs might lower yield the differences were not significant. Nitrogen immobilization differences and greater varibility in nitrogen levels casts significant doubt on the dependability of the 1984 yield data.

CONCLUSIONS AND RECOMMENDATIONS

Molinate Residues

Conclusions

Net discharge declines with longer WHPs (treatments 6 and 7). At a given WHP net discharge declines with lower tail water flows.

A substantial portion of the total net discharge usually occurred on the first day or two after the WHP. The first day usually had the peak discharge rate (g/day).

Water depth does not affect net discharge at the end of an 8 day WHP or after the WHP.

An 8 day WHP with low water flow was nearly as effective in reducing net discharge as the 16 day WHP.

Increased use of preflood applied molinate with a corresponding decrease in postflood applications would reduce net discharge substantially.

Short-term fluctuations in field concentrations make the interpretation of analytical data difficult and imprecise.

Recommendations

Avoid complete drainage or high tailwater flows after the WHP as this results in high net discharges.

Use moderate WHPs with water flow restrictions rather than longer WHPs. This will allow greater grower flexibility.

Encourage increased use of preflood molinate by reducing the required WHP. (Preflood residue levels do not warrant an 8 day WHP).

Reliance on intermittant sampling results should be reduced. Improvements are needed in field sampling methods that permit an increase in sampling stations and minimize the time between samples in some practical way.

Pest Growth and Damage

Conclusions

Early season shallow water encourages rapid broadleaf and sedge weed growth, while deep water suppresses growth. Some species are affected more than others. Weed control was generally poorer in shallow water.

Drainage after the WHP inhibited the growth of some aquatic weeds but stimulated smallflower umbrellaplant and watergrass. Weed control was generally poorer for several weed species, including watergrass.

WHP had no effect on weed growth and development.

Mosquito larval (Culex tarsalis) development was faster in the deep and deep drain treatments (5 and 8) and slower in shallow water (treatment 2).

Pathogen and invertebrate pest populations were too low to determine water management effects.

Recommendations

Avoid shallow water since this encourages weed growth and competition and increases reliance on herbicides to acheive adequate weed control.

Avoid drainage after the WHP since this encourages the growth of highly competitive weeds.

Rice Growth and Yield

Conclusions

Shallow water speeds early season rice growth and development as measured by leaf stage, tiller production and biomass accumulation, while deep water slows them somewhat.

Shallow water during the first half of the season also delays heading and maturity compared to deep water.

Drainage after the WHP slowed rice growth as measured by height, tiller production and biomass accumulation compared to continuous flood.

WHP had no effect on rice growth and development. However, no problems occurred during the WHP. Had problems arisen (ie. algae, salinity, toxic gases and acids, rice water weevil, etc.) rice growth and yield could have been affected substantially.

The moderate water depth resulted in the highest yield because it provided a happy "medium" for rice growth and weed suppression.

Yields were lowest in shallow and drained treatments since weed control was poorest under these management schemes.

WHP had no adverse effect on rice yield. Again no production problems arose that could have precluded us from holding water long periods. Had problems developed, without some water management flexibility, yield reductions could result.

Recommendations

Use moderate water depths (4-5 inches) during the early season to encourage good rice growth and help suppress weed growth. Avoid drainage or large fluctuations in water depth to obtain better weed control and encourage rice growth.

If specific problems do not arise WHPs do not appear to be harmful to rice. In the absence of problems growers should voluntarily hold water beyond the required WHP as long as is practical. This should reduce the need for regulatory agencies to impose mandatory restrictions which do not allow growers the same flexibility.

INTRODUCTION

Water management is one of the most important management variables in California rice production. Water management practices can greatly effect rice stand establishment, rice pests, the fate of pesticides and rice yields.

For example, when rice seedlings are stressed from adverse environmental conditions, chemical toxicities or pest damage, field water is sometimes lowered or drained to save the developing plants. The release of significant amounts of field water before, and to a lesser extent after the required pesticide water holding period (WHP) for these and other reasons increases the amount of pesticide residue levels in the agricultural drains, tributaries of the Sacramento River, and the river itself.

Barnyardgrass (Echinochloa sp.), commonly referred to as watergrass, is the most widespread and troublesome weed in California rice. Throughout most of the rice producing areas of California the grass herbicides molinate and thiobencarb, sold under the trade names Ordram and Bolero , respectively, are used to control this weed. Thiobencarb s also used to control smallflower umbrellaplant (Cyperus difformis) and sprangletop (Leptochloa fascicularis), two other problem weeds. Competition studies have shown that a population of 3 watergrass plants/square foot reduces rice yields by 50% when grass herbicides are not used. This illustrates the importance of molinate and thiobencarb for the control of this weed and in California rice production.

Cultural methods of weed control, such as cultivation during seedbed preparation, fertilizer management, use of weed-free seed and water management are all important components of a complete weed control program. By themselves these methods are only partially effective in controlling weeds. Chemical methods, used alone, are usually not completely effective either. Weed control is best when chemical and cultural methods are combined together and used in an integrated program.

Residues of molinate and thiobencarb have been detected in rice irrigation drain water since 1980 and have been associated with water quality problems in the agricultural drains and the Sacramento River. Herbicide residue monitoring studies conducted by the Department of Fish and Game and others have shown that molinate residues in the agricultural drains have reached levels (hundreds of parts per billion) known to be toxic to carp. Fish losses occurring in the Colusa Basin Drain in the early 1980's during the rice herbicide use season (May-June) have been associated with molinate residues. Analyses of carp and catfish flesh have shown molinate residues to reach 1800-2200 ppb during the use season and that these residues dissipate soon thereafter. Thiobencarb is also known to be toxic to aquatic life. Residues of molinate and thiobencarb have been detected in Sacramento River water and concern for migratory fish and other aquatic life in the state water system has been expressed. Additionally, residents of the City of Sacramento, which draw potable water from the Sacramento River, are concerned that they may be at risk from residues present in the water.

This study was conducted to determine the effect of rice field water management practices on the dissipation and discharge of molinate residues and the agronomic and pest management aspects of rice production in California. We have taken an integrated approach hoping to identify water management practices that would minimize the off-site movement of molinate residues from rice fields, to find practices that would minimize weed competition and other pest damage and to avoid any adverse effects on rice growth. The methods and results sections of this report cover the 1985 portion of the study. The summary, conclusions, and discussion sections cover the entire 2 year study. Persons interested in a complete review of our 1984 results should read our Preliminary Report on Evaluation of Rice Water Management Practices on Molinate Dissipation, Rice Pests and Production, 1985. Agronomy Progress Report No. 178, University of California, Davis.

MATERIALS AND METHODS

Experimental Design and Treatments

In 1984, a field trial was initiated on 20.8 acres near Williams, California, to study rice water management practices and their effect on molinate residues in irrigation drain water and on rice pests and rice production. Figure 1 shows the site layout with irrigation ditches, drains, levees, irrigation weir boxes, and plots indicated. Twenty-eight plots (basins), each with separate water inlet and outlet boxes, were established at the site. Twenty-four of these plots, each measuring approximately 60 x 425 ft. (0.59 acres) and numbered 1-24, were used for the primary study, while the others, measuring 47 x 425 ft. (0.46 acres) and numbered 1A-4A, were used in a separate and secondary study.

Eight water management treatments (Table 1), each replicated 3 times and arranged in randomized complete block design, were assigned to plots 1-24 (Figure 1). Treatments were designed to study the effect of water depth, drainage vs. continuous flooding and water holding periods on molinate residues, pests, and rice production.

All treatments received a postflood aerial application of molinate at 4 lbs. a.i./acre when watergrass reached the 2-leaf stage. In a separate but related study, plots 1A, 3A, and 4A received a preflood molinate treatment (3 lbs. a.i./acre) incorporated into the soil. Water in these plots was managed identically to treatment number 3. In addition to these herbicide treatments, standard pest control practices were used over the entire trial area (see field management practices).

Designated areas within plots were assigned to researchers for their monitoring activities (Figure 2). Rice, weed and disease monitoring were conducted in treatments 1-8 while mosquito monitoring was conducted in treatments 2, 4, 5 and 8. Other invertebrates were not monitored in 1985 because of their low populations in 1984. Rice and weed monitoring was also conducted in plots 1A, 3A and 4A as part of a separate study.

Variety x water management studies were also carried out in treatments 2, 4 and 5, but are not discussed in this report.

Field Management Practices

In the summer of 1983, the trial site was laser leveled to 0.022 feet fall per 100 feet in the east/west direction, with no fall in the north/south direction. The field was then chiseled and disced. After the east/west levees were installed, each plot was triplaned to fill in the borrow pit areas. Once these operations were complete, the north/south levees and boxes were installed.

Following the 1984 season the rice straw and stubble from the first year of the study was burned. In the spring of 1985, the seedbed of each plot was prepared by chiseling, discing, triplaning and harrowing. The

WATER MANAGEMENT TRIAL

COLUSA COUNTY

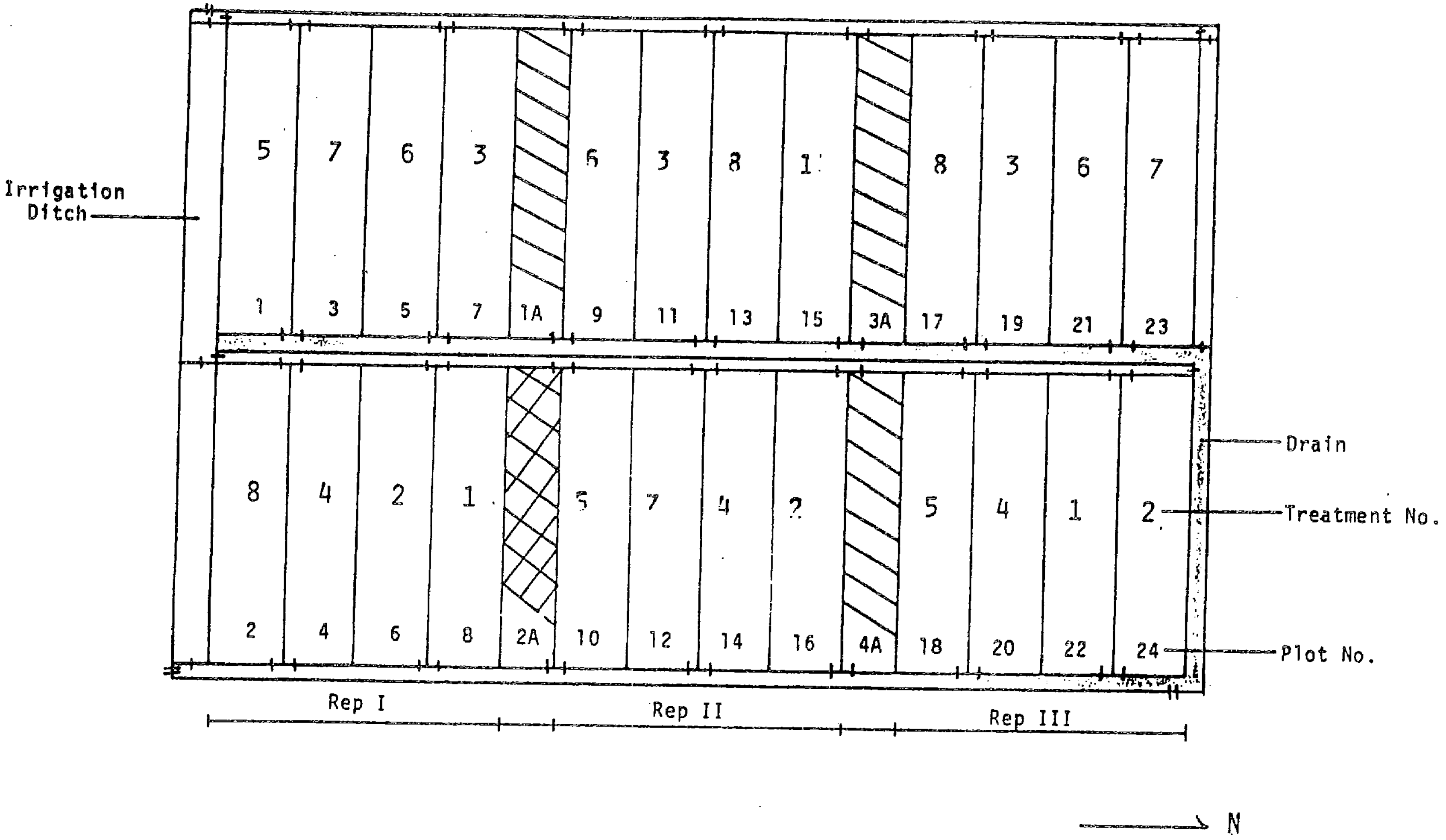


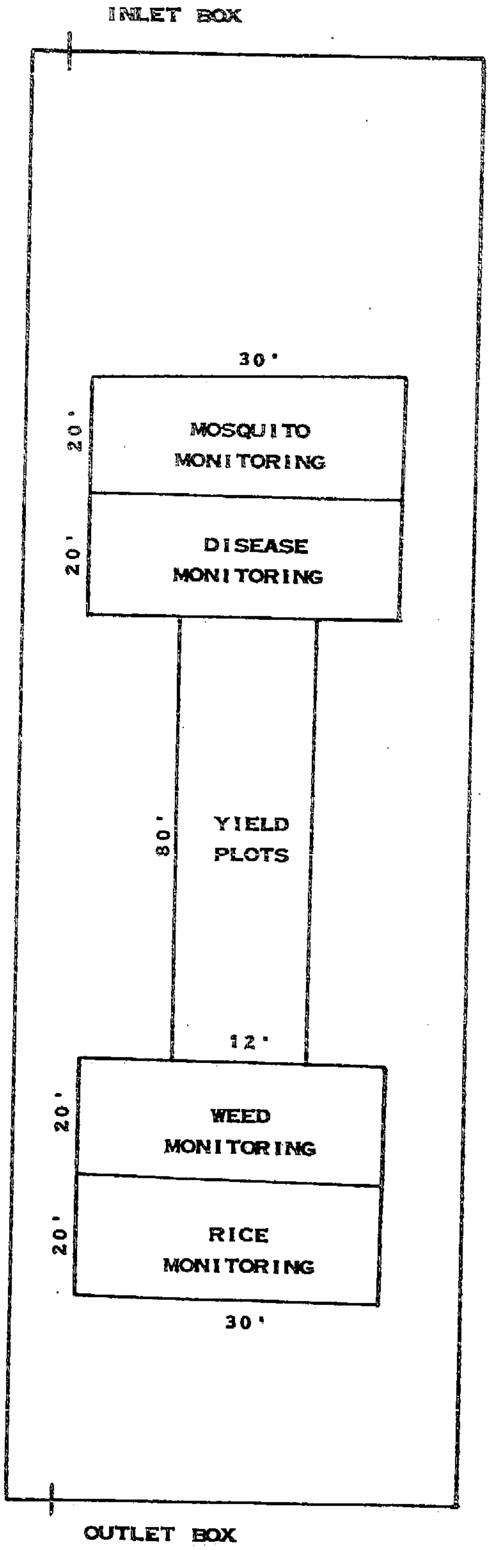
Figure 1. EXPERIMENTAL DESIGN AND LAYOUT SHOWING PLOT LOCATIONS AND TREATMENT RANDOMIZATION.

Table 1. WATER MANAGEMENT TREATMENTS SHOWING PLOT WATER DEPTHS, WATERHOLDING PERIODS, AND RELEASE OR DRAINAGE OF WATER.

WATER MANAGEMENT TREATMENT NO.	WATER LEVEL PRIOR TO MOLINATE APPLICATION (Inches)	WATER LEVEL DURING WATER HOLDING PERIOD (Inches)	WATER HOLDING PERIOD (WHP) (days)	WATER RELEASE (R) OR DRAINAGE (D) AFTER WHP	WATER LEVEL AFTER WPH (Inches)	WATER LEVEL AFTER PANICLE INITIATION GROWTH STAGE (Inches)
1	1 - 3	5 - 7	8	R	1 - 3	5 - 7
2	1 - 3	1 - 3	8	R	1 - 3	5 - 7
3	3 - 5	5 - 7	8	R	3 - 5	5 - 7
4	3 - 5	3 - 5	8	R	3 - 5	5 - 7
5	5 - 7	5 - 7	8	R	5 - 7	5 - 7
6	3 - 5	5 - 7[1]	16	R	3 - 5	5 - 7
7	3 - 5	5 - 7[1]	32	R	3 - 5	5 - 7
8	5 - 7	5 - 7	8	D	0 for 10 days then 5 - 7	5 - 7

[1] Water level 5-7 inches for the first 8 days of WHP, then the water level was lowered by subsidance to 3-5 inches for remainder of WHP.

Figure 2. MONITORING AREAS WITHIN A REPRESENTATIVE PLOT.



spiketooth harrow served to incorporate the nitrogen and phosphate fertilizer which was previously applied by air. Harrowing also incorporated the preflood applied molinate in plots 1A, 3A and 4A. Flooding of the plots was initiated April 23 (6 p.m.) and completed on April 26 (7 a.m.). Water depths were stabilized at their designated levels by the time the rice was seeded on April 28. Plot water depths differed by 0.1 feet between the east and west ends, with the eastern end being deeper. In addition, soil movement occurring during seedbed preparation and the presence of clods also resulted in variations in water depth within plots. Water levels in plots 4, 10 and 12 deviated from their designated depth on a few occasions in 1985 due to crayfish problems. During the water holding period water depths subsided from their designated levels due to evapotranspiration and percolation. Water was added to plots at day 4 of the holding period to replace these losses. On June 10 (after the end of all WHP) water was lowered to 3 inches in all treatments to apply the broadleaf herbicide MCPA on June 11. Water depths were reestablished on June 12.

Pesticides applied to the trial site included methyl parathion, molinate, and MCPA; the former for crayfish control and the latter two for weed control. A postplant application of nitrogen was applied immediately following the MCPA application.

Table 2 lists and describes the general management practices carried out at the trial site.

Field Parameters

Preplant soil samples, collected from each plot, were taken on April 10, 1984 to determine the status and uniformity of soil properties at the site. Samples were dried and analyzed by the Cooperative Extension Soil, Water and Plant Analysis Laboratory at U. C. Davis.

Plot water depths based on the readings from staff gauges located near the outlet box of each plot were recorded once a day at noon. These staff gauges were set at survey marks established by Lux Engineering, Inc.

Water flow rates were measured using a 90° V-notch weir installed on the downstream side of each outlet box. Stilling wells along with staff gauges were installed behind the V-notch (Appendix I) to determine the head of water flowing through it. Water flow readings were also recorded once a day at 12 noon. Water flow readings from 1984 indicated that the average flow at 8 a.m. and 4 p.m. would approximate the mean daily flow for the day. Hence we decided to measure flow once a day at 12 noon. Correlation coefficients between the mean daily (mean of a.m. and p.m.) manual readings from 1984 and the Stevens Stage Recorder readings from 1984 (mean of readings taken every 4 hours) averaged 95%; regression analysis between these two variables gave an average r-squared value of .90 (Appendix II). The correlation coefficients and r-squared values between the a.m. or p.m. manual readings and the recorder readings were slightly less, but also high. Because of the high degree of correlation between the manual water flow readings and the Stevens Stage Recorder readings only manual readings are reported for 1985.

Table 2. MANAGEMENT PRACTICES FOR THE TRIAL SITE IN 1985.

EVENT, MATERIALS AND RATES	DATE	COMMENTS
Chisel seedbed	4-08-85	
Disc seedbed	4-12-85	
Triplane seedbed	4-16-85	
Apply nitrogen fertilizer (Urea) 134 lbs. n/a	4-22-85	Incorporated w/harrow
Apply starter fertilizer (18-46-0) 27 lbs. n/a + 69 lbs. P_2O_5/a	4-22-85	Incorporated w/harrow
Apply molinate 3 lbs. a.i./a to plots 1A, 3A and 4A by ground	4-22-85	Incorporated w/harrow
Harrow seedbed	4-22-85	Spiketoothed harrow
Start to flood	4-23-85	6 p.m.
Completely flooded	4-26-85	7 a.m.
Start water holding period (WHP) for preflood molinate plots	4-26-85	7 a.m.
Seed trial (S-201) 175 lbs./a	4-28-85	12 noon
Installed micrologger weather station	4-29-85	Water and soil probes monitor replication no. 2
Apply methyl parathion, 1.0 lbs. a.i./a	4-29-85	6 p.m.
Start to raise water depth in treatment 1, 3, 5, 6, 7 and 8 plots to 6-7 inches for WHP	5-7-85	
Apply molinate, 4 lbs. a.i./a	5-9-85	7 a.m.

Table 2. (continued)

EVENT, MATERIALS AND RATES	DATE	COMMENTS
Start of postflood molinate WHP's	5-9-85	7 a.m.
End of 8 day WHP	5-17-85	7 a.m.
Start to lower water for MCPA application in treatments 5 and 8	6-09-85	
End 32 day WHP	6-10-85	
Lower water for MCPA application in all treatments	6-10-85	Lowered water in all plots to 3 inches
Apply MCPA 0.75 lbs. a.i./a	6-11-85	6 a.m.
Apply nitrogen fertilizer (Ammonium Sulfate) 31.5 lbs. n/a	6-11-85	12 noon
Reestablish water depths in all treatments	6-12-85	6 a.m. to 7 p.m.
Panicle initiation	7-03-85	Approximate date
Start to increase water level in all treatments to 6-7 inches	7-06-85	Increased over a 4 day period
Apply methyl parathion 1.0 lbs a.i./acre	7-19-85	
50% heading date		Variable among plots
Shut off water to plots	9-05-85	
Drain water	9-08-85	
Harvest	10-01-85	Started on 9-25 but moisture to high

Temperature was measured using Maximum/Minimum thermometers placed in cloth bags and submerged in the water in all treatments. Maximum and minimum temperature readings were recorded daily until July 10. Campbell Instrument Microloggers were also used to record soil, water and air temperatures in plots from replication number 2. Data from this source is unavailable at this time. As part of the intensive herbicide residue monitoring component of this study, soil, water and air temperatures, humidity, water pH and dissolved oxygen were recorded for the 24 hours following the molinate application (see Herbicide Residue Monitoring and Analysis section for further discussion).

Herbicide Residue Monitoring and Analysis

Sampling and Handling of Samples

Molinate residue monitoring was divided into two separate phases: general monitoring of all plots and intensive monitoring of one plot. The general monitoring phase consisted of sampling all plots on the first, second, fourth, eight, twelfth, sixteenth, twenty-fourth and the thirty-second day after the postflood molinate application (Table 3). Exceptions to this schedule were the twelve and sixteen day samples from treatment 8 plots (#2, 13, 17) which were dry as scheduled. Background samples were taken from plots 5, 6, 17 and 18 the day before the application. In addition, water samples were taken at the north and south ends of the two irrigation supply canals at each sampling date. Plots 1A, 3A and 4A, which were part of a separate study, received a preflood molinate application. They were sampled on the third, sixth, eleventh and thirteenth days after complete flooding (Table 3) ending when the postflood molinate application was made. Intensive monitoring was conducted in plot 2. Water and soil samples were collected near the outlet starting at 32 hours after the postflood molinate application (to allow for complete release of molinate from the formulated granule) then every 2 hours during the day and every 3 hours at night. After collecting the soil samples they were allowed to settle for 1 hour before the excess water was decanted.

All samples were collected near the outlet box of each plot using a stainless steel beaker and placed in teflon capped rectangular bottles and stored at -30°C until analysis, one to two weeks later. Samples were uncolored and clear as suspended sediments settled before analysis began.

Residue Analysis

Postflood general monitoring analyses were performed by the Trace Analysis Laboratory of the Department of Environmental Toxicology, U.C. Davis (TAL/UCD). All other samples were analyzed in the laboratory of Dr. D. G. Crosby, Department of Environmental Toxicology, U.C. Davis (DGC/UCD). Both laboratories employed a rapid and precise water extraction method developed at DGC/UCD, as follows:

1. A C_{18}Bond-Elut^{TM} cartridge under vacuum was rinsed twice with 1.5-2 ml methanol then rinsed twice with 5 ml of distilled water.

Table 3. 1985 MOLINATE MONITORING SCHEDULE

			NUMBER OF SAMPLES PER TREATMENT #								SUB-	INLET
DAY	DATE	FIELD ACTIVITY	1	2	3	4	5	6	7	8	TOTAL	SAMPLES
-13	4/26	Flooding complete										
-10	4/29	Day 3 Preflood samples									4	
- 7	5/02	Day 6 Preflood samples									4	
- 2	5/07	Day 11 Preflood samples									4	
0	5/09	Day 13 Preflood samples									4	
0	5/09	Postflood background samples	1				1	1		1	4	
0	5/09	Molinate application										
1	5/10	Day 1 samples	3	3	3	3	3	3	3	3	24	4
1-2	5/10	Intensive survey samples								24*	24	
2	5/11	Day 2 samples	3	3	3	3	3	3	3	3	24	4
4	5/13	Day 4 samples	3	3	3	3	3	3	3	3	24	4
8	5/17	Day 8 samples	3	3	3	3	3	3	3	3	24	4
12	5/21	Day 12 samples	3	3	3	3	3	3	3		21	4
16	5/25	Day 16 samples	3	3	3	3	3	3	3		21	4
24	6/02	Day 24 samples	3	3	3	3	3	3	3	3	24	4
32	6/11	Day 32 samples	3	3	3	3	3	3	3	3	24	4
									TOTALS		230	32

*Includes 12 water + 12 soil samples

2. Each sample (20.0 gm) was pulled through the cartridge over a one minute period, followed by a 3 ml distilled water rinse.

3. The molinate-laden cartridge was eluted with 1.00 ml ethyl acetate and clinical centrifuging at full speed for one minute.

4. This extract was quantitatively transferred to vials for GLC analysis.

For the soil samples, the following procedure was used:

1. A sample (50 gm) in 100 ml of acetonitrile was macerated with a Polytron blender at 10,000 rpm for 1 minute.

2. The sample was filtered through Celite 545 chromatographic aid and rinsed with 50 ml of acetonitrile.

3. The sample, including the Celite, was re-macerated and filtered as above.

4. The pooled filtrate was concentrated to dryness using a rotary evaporator and then a N_2 evaporator.

5. The dried residue was taken up in 0.5 ml of ethyl acetate for GLC analysis.

The gas chromatograph employed for the analysis of postflood general monitoring samples was a Varian Model 6000 equipped with a N-P detector and a 5% OV-101 packed steel column (50 cm x 3 mm o.d.). Analysis conditions were: column=180°C, injector=220°C, detector=250°C, He carrier gas=15 ml/min, H_2=4.3 ml/min, air=175 ml/min, analysis time= 1 min.

Confirmation of molinate residue was performed on a Varian Model 3300 gas chromatograph equipped with a flame ionization detector and a DB-1 open-tubular glass column (30 m x 0.25 mm i.d.). Analysis conditions were: column=65°C held for 1.5 min, raised to 150°C at 20°C/min, then raised to 300°C at 10°C/min, splitless injector=220°C with purge vent closed for the first minute, detector=320°C, He carrier gas=2 ml/min, He makeup gas=14 ml/min, H_2=30 ml/min, air=300 ml/min, analysis time=30 min. The presence of molinate was also confirmed by mass spectrometry.

Recovery Study

TAL/UCD performed a recovery study by fortifying preapplication field water with 0.0042, 0.042, 0.42 and 4.2 ppm molinate. The average recoveries were 95.2, 94.6, 94.6 and 99.9%, respectively. DGC/UCD obtained an average recovery of 78.3% from preapplication soil fortified with 0.125 ppm molinate.

Pest Monitoring

Cooperating researchers were assigned designated areas to conduct their pest monitoring activities (Figure 2). Pest monitoring methods are described by pest grouping as follows:

Weeds

Watergrass population counts were not made in 1985 since 1984 results showed the population to be very low. Broadleaf and sedge weed population counts were made at 39 DAS just before the broadleaf herbicide application. Three subsample counts were made per plot using a 0.75 sq. ft. sampling ring. On June 27 after all herbicides had been applied plots were subjectively rated for weed control by species on a scale of 1-10 with 1= poor and 10= excellent control. A second rating was made on August 2 for watergrass and roughseed bulrush.

Several broadleaf weed species were sampled at 20, 30 and 40 DAS to monitor any growth differences due to water management treatments. Watergrass was not sampled because of its very low population. Samples consisted of 15 plants of a given species from each plot which were placed in a plastic bag and stored in a refrigerator until processing 1-7 days later. Growth was measured by determining plant height, leaf stage or number of leaves, tiller or branch number and sample dry weight (shoots and roots). Plant height was measured in centimeters from the crown to the tallest leaf. The leaf stage was determined by counting the number of leaves on the main stem. Partially developed leaves were given a score of 0.10, 0.20, 0.50, 0.80 and 0.90 if expanded 1-9%, 10-35%, 36-64%, 65-90% and 91-99%, respectively. For example, a plant having four fully expanded leaves and a fifth leaf expanded 30% would be at leaf stage 4.2. Tiller number was simply the number of tillers per plant excluding the main stem. Leaf number is simply the leaf stage plus tiller or branch number combined. After completing the above measurements plants were washed using sieve plates and dried in a low temperature oven. Dried samples were weighed shortly after removal from the oven to avoid sample rehydration.

Diseases

Samples for stem rot and aggregate sheath spot inoculum level and disease severity assessment were taken from each plot.

To determine pathogen inoculum levels, preflood soil samples were collected at random from the seed bed (top 3 inches) of each plot. Samples from each plot were combined, then five sub-samples were processed by established methods to determine the number of viable sclerotia of _Sclerotium oryzae_ (stem rot) and _Sclerotium oryzae sativae_ (aggregate sheath spot) per gram soil.

Random plant samples taken from the area designated for sampling were collected when plots were drained for harvest. Each sample consisted of at least 100 tillers. Stem rot severity was rated by methods described previously and expressed as 1 = healthy - 5 = severe. Aggregate sheath spot was rated on the basis of distance disease developed up the tiller from the base and expressed as the mean for the total tillers rated.

Rice seedlings were evaluated for seed rot and seedling disease. Fifteen plants per plot were sampled 10 days after seeding and subsequently rated positive or negative for the disease.

Mosquitoes

Four of the eight water management treatments were selected to monitor mosquito populations, survival rates and relative development. Mosquito predators were also monitored. Treatments 2, 4, 5 and 8 were sampled on July 1. A team of three people sampled each plot, taking 3 dips with a standard 1 pint mosquito dipper at each stop and 10 stops per plot. The samples were concentrated through a fine mesh net and transported back to the laboratory for invertebrate fauna counts and algal descriptions. Water samples for chemical (pH, Ca, Mg, Na, Cl, CO_3 + HCO_3, NO_3N, B, SO_4-S, PO_4-P) analysis were taken and were analyzed by the Cooperative Extension Soil, Water and Plant Analysis Laboratory at U.C.D.

Fine mesh predator exclusion sentinel buckets containing 20 first instar colony _Culex tarsalis_ larvae were set out twice (June 25-July 5 and July 12-22) to monitor mosquito survival and relative development between the treatments. The second sentinel trial was aborted when parathion was applied at the inlet boxes on July 19 killing all larvae. Buckets were set out in treatments 2, 4, 5 and 8 in replicate 1 and treatments 2, 4, and 5 in replicate 2. Three buckets were used per plot.

Rice Monitoring

Rice population counts and plant sampling were conducted in the rice monitoring area of each plot while final plant height, lodging and yield were taken from the yield area (Figure 2).

Rice population counts were made at 20, 30 and 40 days after seeding (DAS). Three subsample counts were taken per plot using a clear plastic cylindrical sampling ring 0.75 sq. ft in size.

Rice was sampled at 10, 20, 30, 40 and 65 DAS to monitor growth differences due to the water management treatments. Samples consisted of 15 plants from each plot placed in plastic bags and stored in a refrigerator until processing 1-10 days later. Rice growth was measured by determining plant height, leaf stage, tiller number and sample dry weight (foliage and roots). At the 65 DAS sampling date, tillers less than 30 cm tall were assumed to be non-fertile and were not counted. Rice was processed the same as the broadleaf weeds.

At heading the yield portion of plots were subjectly rated to determine the date of 50% heading. Shortly before harvest plant height was measured and the number of panicles per unit area was determined. Three subsample counts were made per plot using the 0.75 sq. ft. plastic cylindrical ring. The panicle count per square foot divided by the 40 DAS rice population count provided an estimate of the final number of fertile tillers per plant.

At harvest, plots (yield area) were rated for lodging on a 1-99 scale with 1=0% lodging and 99=100% lodging. Two yield sub-plots (7.5 ft wide by 40 ft long) were harvested in each plot using a Sweco 324 plot combine with grain weight and moisture determined on site. Wet weight yields were adjusted to 14% moisture.

RESULTS

Field Parameters

Analysis of preplant soil samples (Appendix III), taken on April 10, 1984 indicated that soil physical and chemical characteristics were relatively uniform over the experimental area. The analysis also indicated that the soil characteristics were as follows: loam or silt-loam texture (SP = 41 - 53%); acidic (pH ranges from 4.9 to 6.3); low Exchangeable Sodium Percentage (ESP =< 1-4%, except plots 2 and 4 at 12 and 8%, respectively); and deficient to marginal in phosphorus (P = 3.3-12.7 ppm).

Summaries of water depth and water flow data by treatment are shown in Appendices IV and V, respectively. Mean minimum and maximum temperatures by time period are shown in Tables 4 and 5, respectively.

Analyses of the water temperature data showed a highly significant linear trend of increasing minimum temperature (manual readings) with increasing water depth during each of the 5 time periods analyzed (Table 4). The analyses also showed a significant or highly significant linear trend of decreasing maximum temperature with increasing water depth in 4 of 5 time periods (Table 5). The other time period had a similar trend but was not significant. Correlation analysis showed a highly significant positive relationship between water depth and minimum temperature and a negative relationship between depth and maximum temperature (Table 6). The water flow and temperature relationship was usually not significant.

Molinate Dissipation and Discharge

The average molinate residue levels and calculated half-lives (t-1/2) obtained from our postflood general monitoring are shown in table 7. Residue levels in water ranged from 1880 to 3950 ppb on day 1 after application, 533 to 713 ppb on day 8, 52 to 173 ppb on day 16 and 5 to 12 ppb on day 32. The following concentration trends are notable: (1) on days 1 and 2 concentrations decreased with increasing water depth; (2) on day 8 before water was released or depths changed, treatment concentrations were not substantially different; (3) on day 12 the shallow water treatments had substantially lower concentrations than the others; and (4) on days 16, 24 and 32, the treatments that were still holding water had higher concentrations than the others. Figures 3, 4 and 5 show molinate dissipation over time.

The half-life of molinate calculated from day 1 to 32 did not differ much among treatments and ranged from 3.5 to 4.1 days (similar to 1984 results). In contrast, the average half-life, calculated only during the WHP, increased with increasing depth (Table 8).

Table 4. MINIMUM WATER TEMPERATURES DURING THE FIRST HALF OF THE RICE SEASON.

TREATMENT	MEAN MINIMUM TEMPERATURE (°F) BY TIME PERIOD [1]				
	1	2	3	4	5
1	51.7	54.9	57.7	59.6	67.7
2	51.3	51.3	57.7	59.4	67.4
3	55.1	56.1	61.7	63.1	70.2
4	54.2	54.4	60.5	61.6	68.7
5	54.8	54.8	61.9	62.7	69.6
6	54.2	55.8	60.9	62.6	69.4
7	54.6	56.0	61.2	62.6	70.3
8	56.0	55.7	55.2	61.1	72.1
C.V. (%)	1.8	1.5	1.2	1.1	1.4
Among treatments	***[2]	***	***	***	***
Among 2, 4, 5	**	***	***	***	*
Linear 2, 4, 5	***	***	***	***	*
Residual		*			
Among 1, 3, 5	**		***	***	*
Linear 1, 3, 5	**		***	***	*
Residual 1, 3, 5	*		**	**	*
1, 3 vs. 2, 4		***		*	
5 vs. 8			***	*	**
Among 3, 6, 7					
Linear 3, 6, 7					
Residual 3, 6, 7					

---

[1] Time periods and conditions were as follows: (1) 4-27 to 5-6, free water surface with water spilling, rice at 0-2 leaf stage; (2) 5-7 to 5-16, free water surface with water being held, rice at 2-4 leaf stage; (3) 5-17 to 5-25, crop canopy at about 10-30%, water drained, spilling or being held, rice at 4 leaf stage to early tillering; (4) 5-26 to 6-10, crop canopy at about 30-60%, water spilling or being held, rice at early to mid-tillering; and (5) 6-11 to 7-5, crop canopy at about 60-90%, water spilling, rice at mid-tillering to panicle initiation.

[2] Level of significance: *($P \geq .95$); **($P \geq .99$); and ***($P \geq .999$).

Table 5. MAXIMUM WATER TEMPERATURE DURING THE FIRST HALF OF THE RICE SEASON.

TREATMENT	MEAN MAXIMUM TEMPERATURE (°F) BY TIME PERIOD [1]				
	1	2	3	4	5
1	88.3	80.8	92.8	90.2	90.0
2	89.0	84.4	93.5	89.9	89.8
3	83.4	81.0	90.2	87.0	88.1
4	84.7	82.5	89.8	85.8	86.4
5	82.9	82.1	88.2	85.7	87.4
6	84.4	81.4	90.6	87.5	87.7
7	84.7	80.9	89.9	86.8	87.3
8	81.4	80.2	88.9	86.1	87.6
C.V. (%)	1.4	1.3	1.9	1.4	2.1
Among Treatments	***[2]	*	*	**	N.S.[3]
Among 2, 4, 5	***		**	**	
Linear 2, 4, 5	***	*	**	***	
Residual 2, 4, 5				*	
Among 1, 3, 5	***		*	**	
Linear 1, 3, 5	***		**	***	
Residual 1, 3, 5	*				
1, 3 vs. 2, 4		**			
5 vs. 8					
Among 3, 6, 7					
Linear 3, 6, 7					
Residual 3, 6, 7					

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[1] Time periods and conditions were as follows: (1) 4-27 to 5-6, free water surface with water spilling, rice at 0-2 leaf stage; (2) 5-7 to 5-16, free water surface with water being held, rice at 2-4 leaf stage; (3) 5-17 to 5-25, crop canopy at about 10-30%, water drained, spilling or being held, rice at 4 leaf stage to early tillering; (4) 5-26 to 6-10, crop canopy at about 30-60%, water spilling or being held, rice at early to mid-tillering; and (5) 6-11 to 7-5, crop canopy at about 60-90%, water spilling, rice at mid-tillering to panicle initiation.

[2] Level of significance: *(P≥.95); **(P≥.99); and ***(P≥.999).

[3] N.S. = not significant.

Table 6. CORRELATION COEFFICIENTS FOR TEMPERATURE AND WATER DEPTH OR WATER FLOW

		MINIMUM TEMPERATURE		MAXIMUM TEMPERATURE	
TIME PERIOD NO.[1]	DATES	WATER DEPTH	WATER FLOW	WATER DEPTH	WATER FLOW
1	4-27 to 5-6	0.74***[2]	-0.14NS[3]	-0.83***	0.14NS
2	5-7 to 5-16	0.76***	-0.28NS	-0.72***	-0.06NS
3	5-17 to 5-25	0.92***	-0.19NS	-0.21NS	-0.27NS
4	5-26 to 6-10	0.72***	0.49*	-0.74***	-0.37NS
5	6-11 to 7-5	0.75***	-0.23NS	-0.36NS	0.63***

[1] Field conditions and rice growth stage for each period was as follows: (1) free water surface with water spilling, rice at 0-2 leaf stage; (2) free water surface with water being held, rice at 2-4 leaf stage; (3) crop canopy at about 10-30%, water drained, spilling or being held, rice at 4 leaf stage to early tillering; (4) crop canopy at about 30-60%, water spilling or being held, rice at early to mid-tillering; and (5) crop canopy at about 60-90%, water spilling, rice at mid-tillering to panicle initiation.

[2] Level of significance: *($P \geq .95$); **($P \geq .99$); and ***($P \geq .999$).

[3] NS = not significant.

Table 7. SUMMARY OF MOLINATE RESIDUES AND HALF-LIVES IN POSTFLOOD-APPLIED PLOTS.

TREAT-	DATA	AVERAGE MOLINATE CONCENTRATION (PPB) ON DAY NO.									$t_{1/2}$[1>]
MENT NO.	TYPE	BKGRD	1	2	4	8	12	16	24	32	(DAYS)
1	AVE		**1880**	**1810**	**1290**	**543**	185	52	21	5	3.48
	S.E.		115	88	94	82	29	10	5	2	0.19
2	AVE	2	**3950**	**3340**	**1610**	**553**	148	78	27	8	3.80
	S.E.		561	272	131	128	12	9	4	5	0.48
3	AVE		**2230**	**2150**	**1720**	**533**	204	57	25	8	3.59
	S.E.		460	317	150	34	58	30	7	4	0.28
4	AVE		**3250**	**2970**	**2000**	**713**	357	85	32	10	3.54
	S.E.		145	143	56	114	39	19	2	2	0.12
5	AVE	7	**2310**	**2100**	**1520**	**703**	339	88	26	6	3.50
	S.E.		98	112	95	95	52	14	2	1	0.06
6	AVE	2	**2180**	**2120**	**1470**	**603**	**325**	**152**	38	8	3.79
	S.E.		127	243	119	126	87	48	11	1	0.20
7	AVE		**2250**	**2300**	**1630**	**643**	**367**	**173**	**53**	**12**	4.07
	S.E.		106	235	78	145	87	36	4	3	0.20
8	AVE	8	**2410**	**2320**	**1660**	**677**	nd	nd	31	11	3.81
	S.E.		151	155	111	99			5	3	0.21

[1>] $t_{1/2}$ was determined by averaging rates from the least-squares fit of data from day 1 to day 32.

nd = not determined, due to dry plot.

Boldface = residues during water-holding period.

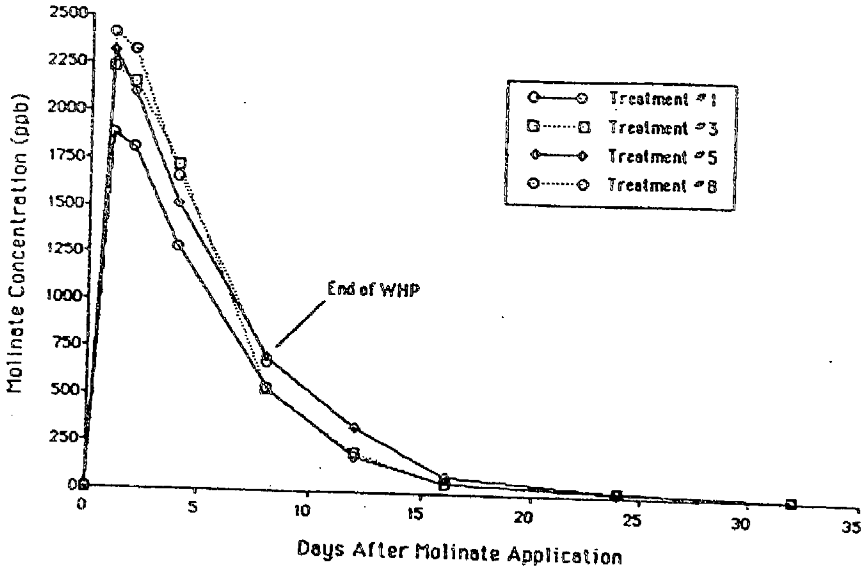


Figure 3. AVERAGE MOLINATE RESIDUES IN TREATMENTS # 1, 3, 5 AND 8 ALL OF WHICH HAD THE SAME WHP (8 DAYS) AND WATER DEPTH DURING THE WHP BUT DIFFERENT AMOUNTS OF WATER RELEASED AND DIFFERENT DEPTHS AFTER THE WHP.

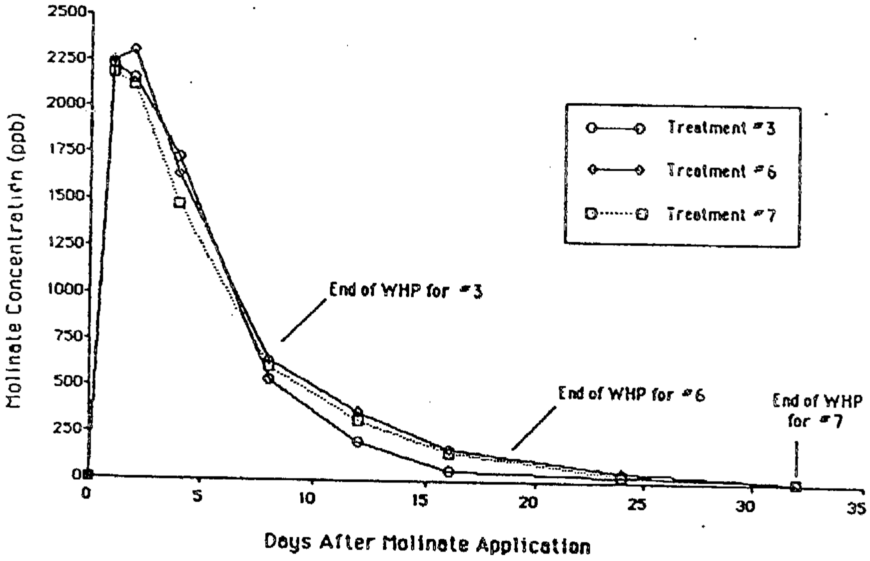


Figure 4. AVERAGE MOLINATE RESIDUES IN TREATMENTS #3, 6, AND 7 ALL OF WHICH HAD THE SAME WATER DEPTHS DURING AND AFTER THE WHP BUT HAD DIFFERENT WHPS.

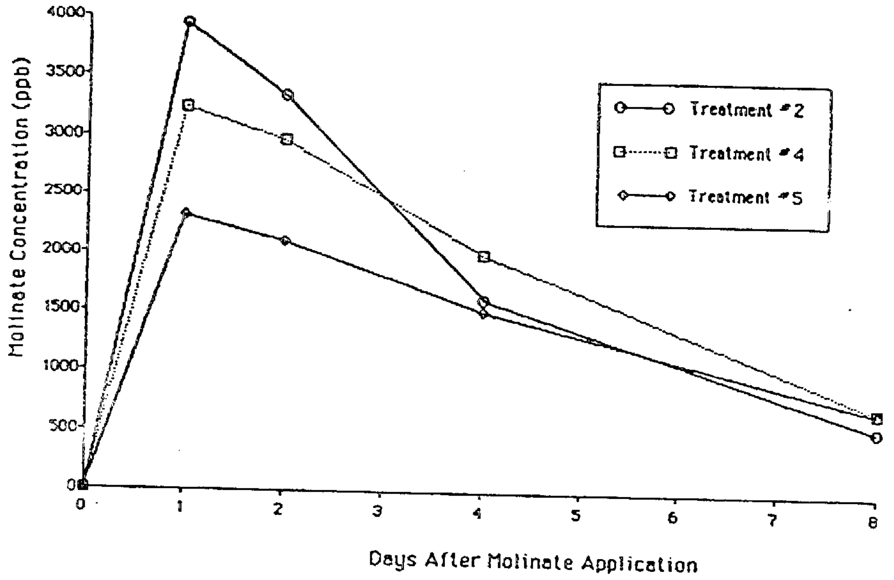


Figure 5. AVERAGE MOLINATE RESIDUES IN TREATMENTS #2, 4 and 5 ALL OF WHICH HAD THE SAME WHP PERIOD (8 DAYS) BUT HAD DIFFERENT WATER DEPTHS DURING AND AFTER THE WHP.

Table 8. MOLINATE HALF-LIFE DURING WHP ONLY.

TREATMENT NO.	WHP DEPTH (inches)	WHP (days)	$t_{1/2}$ (days)[1]	S.E.[2]
2	1-3	8	2.41	0.13
4	3-5	8	3.15	0.31
1	5-7	8	3.81	0.40
3	5-7	8	3.37	0.38
5	5-7	8	4.03	0.35
8	5-7	8	3.70	0.25
6	5-7[3]	16	3.78	0.51
7	5-7[3]	32	4.07	0.20

[1] $t_{1/2}$ was obtained by averaging rates from the least-squares fit of data during the WHP.

[2] Correlation coefficients were 0.97-1.00 for all rate curves.

[3] Water level 5-7 inches for first 8 days of WHP, then lowered by subsidance to 3-5 inches for remainder of WHP.

The average net molinate discharge by treatment has been estimated and is shown in figure 6. Net discharge was highest with early discharge and high water flow rates (i.e. 8 day WHP followed by complete drainage - treatment 8) and lowest with late discharge and moderate water flow rates (32 day WHP followed by water release -treatment 7). At a given water holding period (i.e. 8 days) net discharge decreased as the amount of water released decreased. Also, it decreased as the WHP increased. Water depth seems to have very little effect on net discharge.

Average daily discharge rates (g/day) decreased as water flow decreased. Discharge rates among treatments with different water depths but similar amounts of water released after the WHP did not differ from one another (Figure 7). Those with less water released after the WHP or a longer WHP had lower discharge rates (Figures 8, and 9).

To generate these estimates, a first-order equation [Conc = $A10^{b(\text{days})}$] describing molinate dissipation from day 8 to 32 was assumed. The dissipation equation was then used to determine the daily molinate concentration, which in turn was multipled by the daily flow rate to obtain the daily net discharge or discharge rate.

Background levels of molinate prior to the postflood application were low (Table 7), yet detectable. Monitoring of the irrigation canals after the application showed that molinate concentrations peaked at day 1, then fell to low levels by day 8. Since the canals were flushed and residues were low by the time regular water inflow was restarted we have concluded that the canals were not a significant source of residues during the postflood monitoring.

Intensive monitoring results for postflood molinate are shown in figure 10. Molinate concentrations in water fluctuated during the day, and less at night. The fluctuations were also out of phase with those in the soil compartment. No correlation to any other physical parameters were observed (data not shown).

The general monitoring results following the preflood application are shown in figure 11 and table 9. Molinate concentrations in water ranged from 65 to 196 ppb at day 3 after flooding, 27 to 50 ppb at day 6, 43 to 50 ppb at day 11, and 24 to 36 ppb at day 13. These residue levels are substantially lower than those for the postflood application. The average half-life, calculated from day 3 to day 13 after flooding, was 10.8 days. This indicates that molinate applied in this manner is much more persistant, lasting about 2.5 times longer than molinate applied postflood into water, yet peak concentrations do not exceed 200 ppb.

Although plot 2A did not receive a preflood treatment it had low residue levels present throughout this part of the study. The most likely explanation for these levels is that the irrigation water was contaminated with molinate or molinate was carried over in the soil from the previous year's preflood treatment.

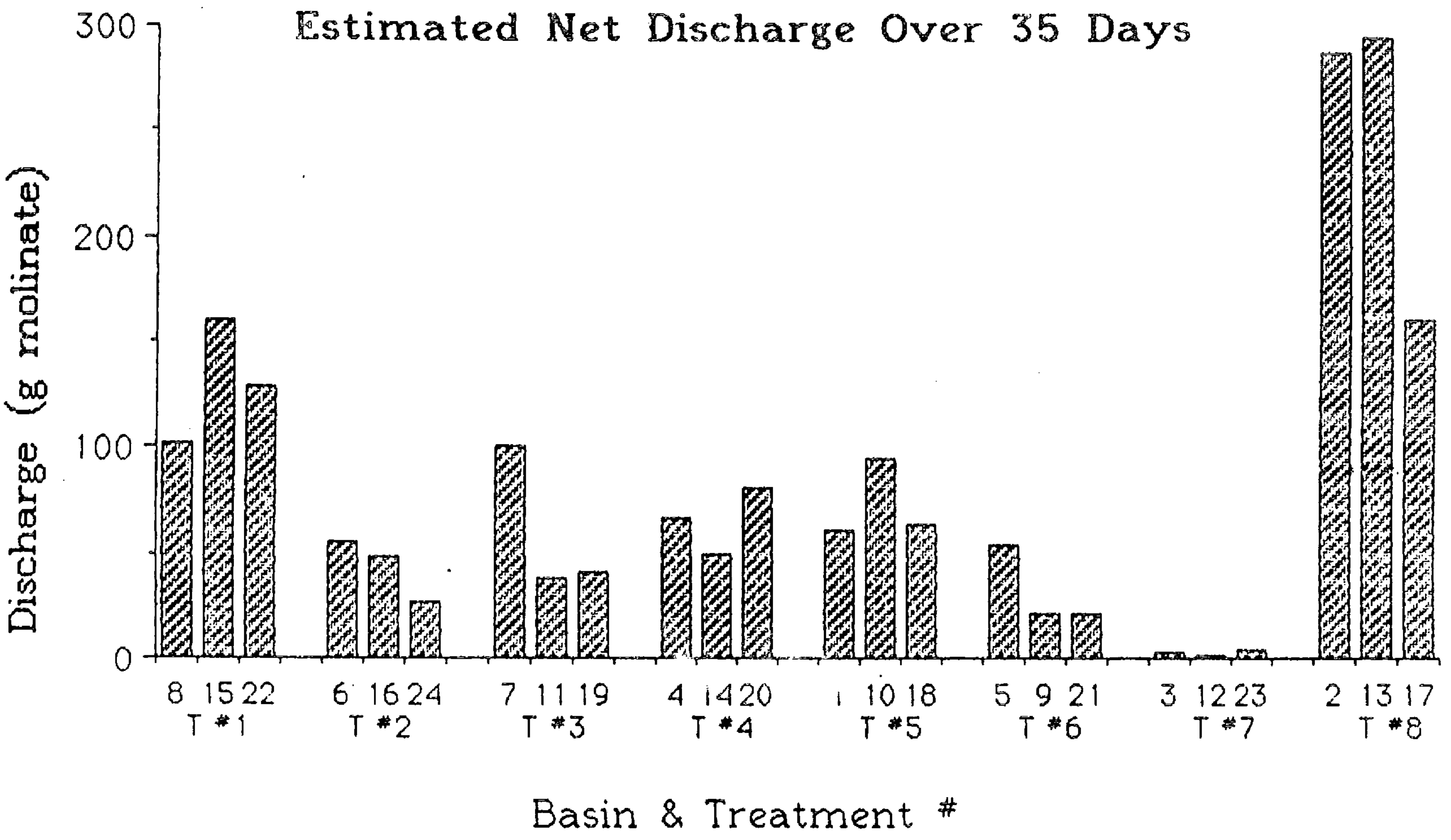


Figure 6. ESTIMATED NET DISCHARGE OF MOLINATE BY TREATMENT AND PLOT (BASIN) FOR 36 DAYS FOLLOWING THE HERBICIDE APPLICATION.

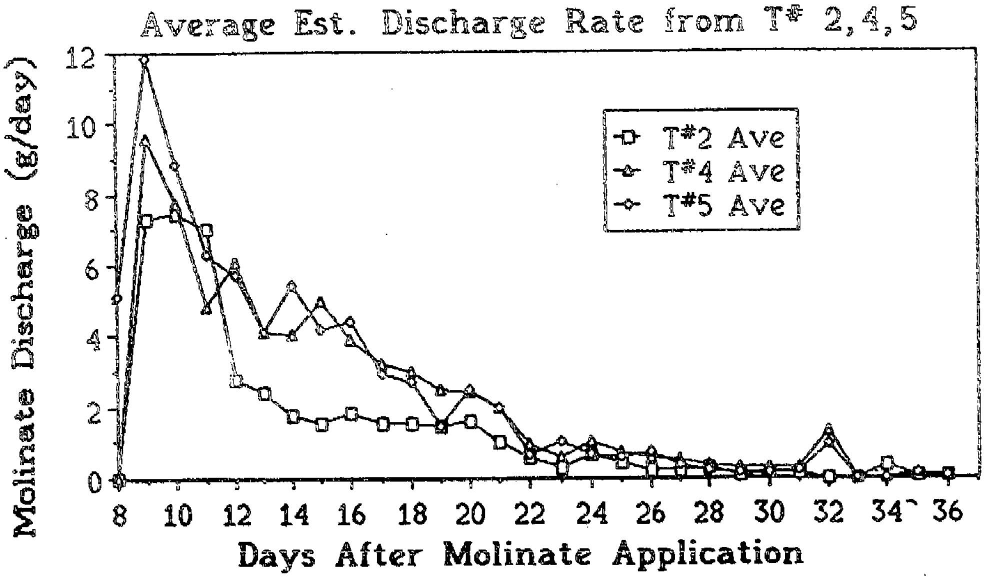


Figure 7. MOLINATE DISCHARGE RATES FOR TREATMENTS 2, 4, AND 5 ALL OF WHICH HAD THE SAME WHP (8 DAYS), BUT HAD DIFFERENT WATER DEPTHS DURING AND AFTER THE WHP.

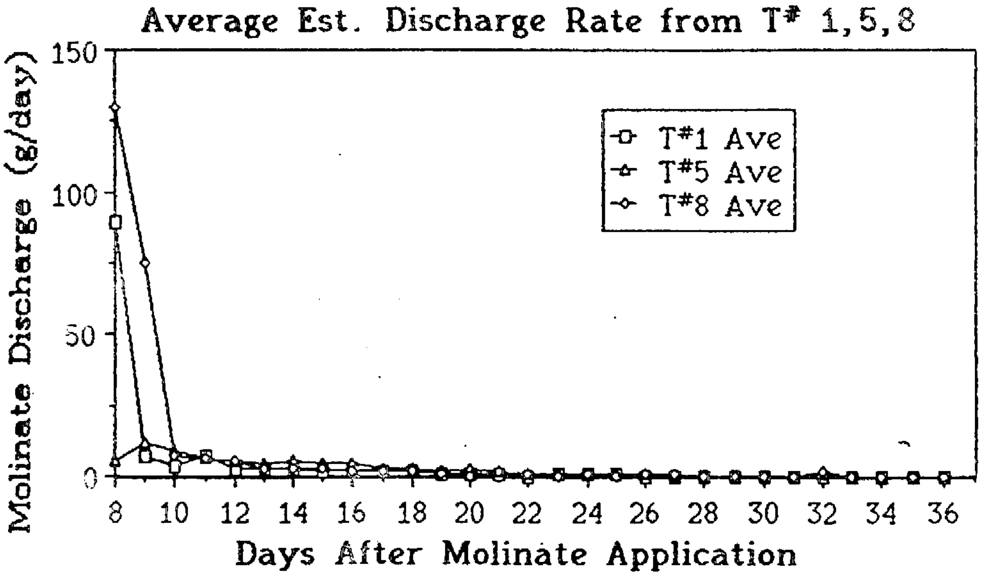


Figure 8. MOLINATE DISCHARGE RATES FOR TREATMENTS 1, 5 AND 8 ALL OF WHICH HAD THE SAME WHP (8 DAYS) AND WATER DEPTH DURING THE WHP, BUT DIFFERENT AMOUNTS OF WATER RELEASED AND DIFFERENT DEPTHS AFTER THE WHP.

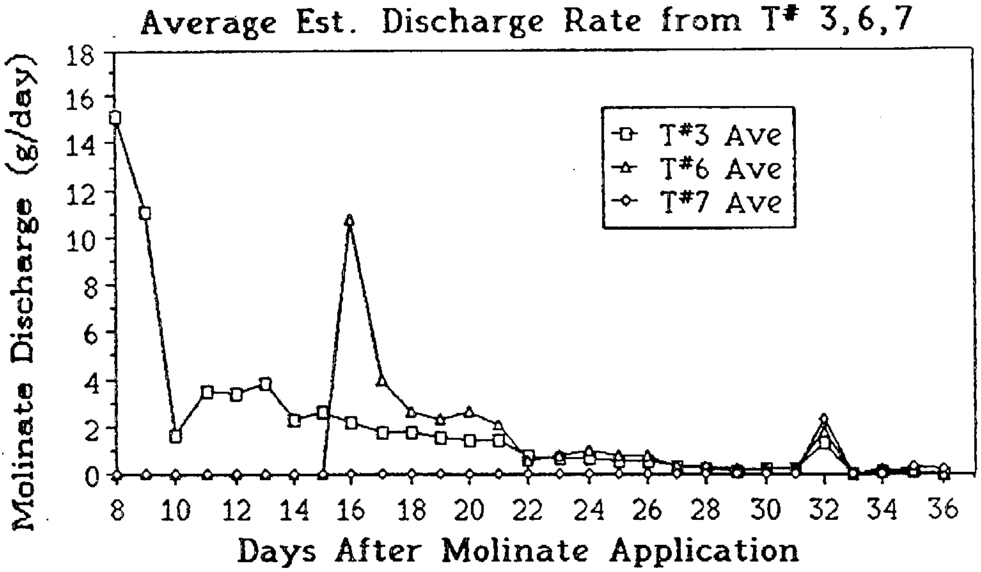


Figure 9. MOLINATE DISCHARGE RATES FOR TREATMENTS 3, 6 AND 7 ALL OF WHICH HAD THE SAME WATER DEPTHS DURING AND AFTER THE WHP, BUT HAD DIFFERENT WHPS.

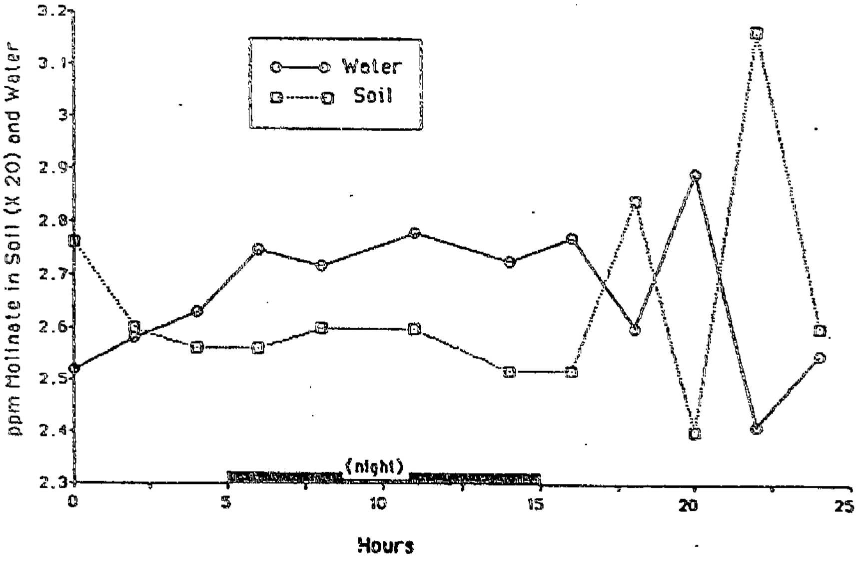


Figure 10. SUMMARY OF INTENSIVE MONITORING OF PLOT #2.

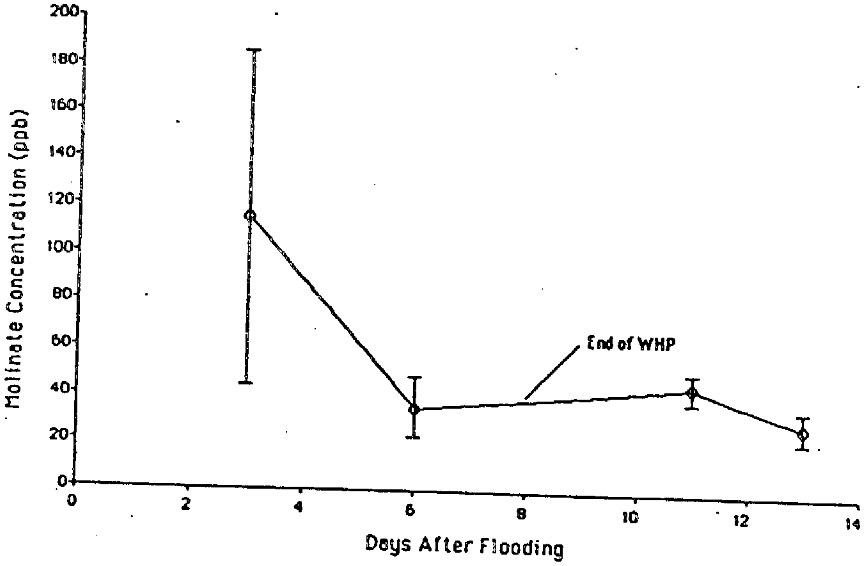


Figure 11. AVERAGE MOLINATE RESIDUES IN PREFLOOD APPLICATION PLOTS.

Table 9. MOLINATE RESIDUES AND HALF-LIVES IN PREFLOOD-APPLIED PLOTS.

PLOT NO.	MOLINATE (ppb) ON DAY# AFTER FLOODING 3	6	11	13	HALF-LIFE[1] (days)	CORRELATION COEFF. (r)
1A	196	50	45	24	3.98	0.90
3A	83	29	50	36	14.44	0.48
4A	65	27	43	28	13.86	0.56
	---	---	---	---	------	
AVERAGES =	115	35	46	29	10.76	
S.E.[2] =	71	13	4	6	5.88	

[1] $t_{1/2}$ was determined by least-squares fit of the data from day 3 to 13.

[2] S.E. = standard error.

Pest Growth and Damage

Weeds

Weed population counts (Table 10) made on June 6 (39 DAS) show the presence and relative abundance of several broadleaf and sedge weed species by treatment. Ducksalad (*Heteranthera limosa*) and waterhyssop (*Bacopa eisenii*) were the most populous broadleaf weeds, while redstem (*Ammania coccinea*) and California arrowhead (*Sagittaria montevidensis* ssp *calycina*) were the least. Smallflower umbrellaplant (*Cyperus difformis*) and roughseed bulrush (*Scirpus mucronatus*), two sedge species, were intermediate in number. The counts show the population of several weed species to be significantly lower in treatment 8 (deep drain) compared to the other treatments. The highest population for several species was in one or both of the shallow water treatments (#1 and 2). This trend was generally not significant, however.

Monitoring for weed growth and development during the early season showed that the sedge and broadleaf species roughseed bulrush (RSBR), smallflower umbrellaplant (SFUP), ducksalad (DS) and waterhyssop (WH) were suppressed by deep water (6-7 inches) and stimulated by shallow water (2-3 inches). Plants grown in shallow water were generally more robust, vigorous and competitive while those in deep water were weak and less competitive by comparison. SFUP was significantly shorter in deep water (Figure 13), while DS and WH were significantly taller but more spindly (Figures 14 and 15). See Appendix VI for the data and analyses. With some exceptions, other growth measurements (leaf number or stage, tiller number, dry weight) were lower in deep water compared to shallow (Figures 12, 13, 14 and 15). See Appendix VI for the data and analyses.

Weed monitoring also showed that drainage for 10 days (after the WHP) affects weed growth. RSBR, DS and WH were significantly shorter at the end of the drain period compared to continuous flood (Figures 16, 17 and 18). The DS and WH height differences disappeared after reflooding. Drainage had no other apparent effect on RSBR or DS growth, but did adversely effect other WH growth parameters (Figure 18). In contrast, drainage temporarily stimulated SFUP growth compared to continuous flood. The differences disappeared shortly after reflooding.

Weed growth differences due to water depth and/or drainage affected weed control. Weed control ratings were generally poorer in shallow water and better in moderate or deep water (Table 11). Ratings were also low in the drain treatment for several weed species, including watergrass.

Table 10. BROADLEAF AND SEDGE WEED POPULATIONS BY TREATMENT.

	WEED POPULATION (PLANTS/FT^2)[1]					
TREATMENT	RSBR	SFUP	DS	WH	RS	AH[2]
1	5.7	12.1	12.6	16.4	1.0	1.3
2	3.3	6.1	13.4	18.5	2.7	0.9
3	2.1	3.4	8.2	14.0	0.8	0.8
4	2.8	3.8	11.2	15.7	1.8	0.9
5	4.4	4.0	9.6	16.1	0.3	0.3
6	4.1	4.7	9.8	17.3	1.6	0.9
7	5.9	6.1	10.2	15	1.1	0.5
8	1.8	6.2	6.2	4.0	0.1	0.0
C.V. (%)	55.9	47.8	21.2	26.9	98.0	41.3
Among Treatments	N.S.[3]	*[4]	*	*	N.S.	**
Among 2, 4, 5						*
Linear 2, 4, 5			*		*	*
Residual 2, 4, 5						
Among 1, 3, 5		**				**
Linear 1, 3, 5		**				***
Residual 1, 3, 5		*				
1, 3 vs. 2, 4						
5 vs. 8				**		
Among 3, 6, 7						
Linear 3, 6, 7	*					
Residual 3, 6, 7						

[1] Population counts were taken June 6 (39 DAS) 5 days before the broadleaf herbicide was applied.

[2] Weed abbreviations are as follows: RSBR = roughseed bulrush; SFUP = smallflower umbrellaplant; DS = ducksalad; WH = waterhyssop; RS = redstem; and AH = arrowhead.

[3] N.S. = not significant

[4] Level of significance: *(P≥.95); **(P≥.99); and ***(P≥.999).

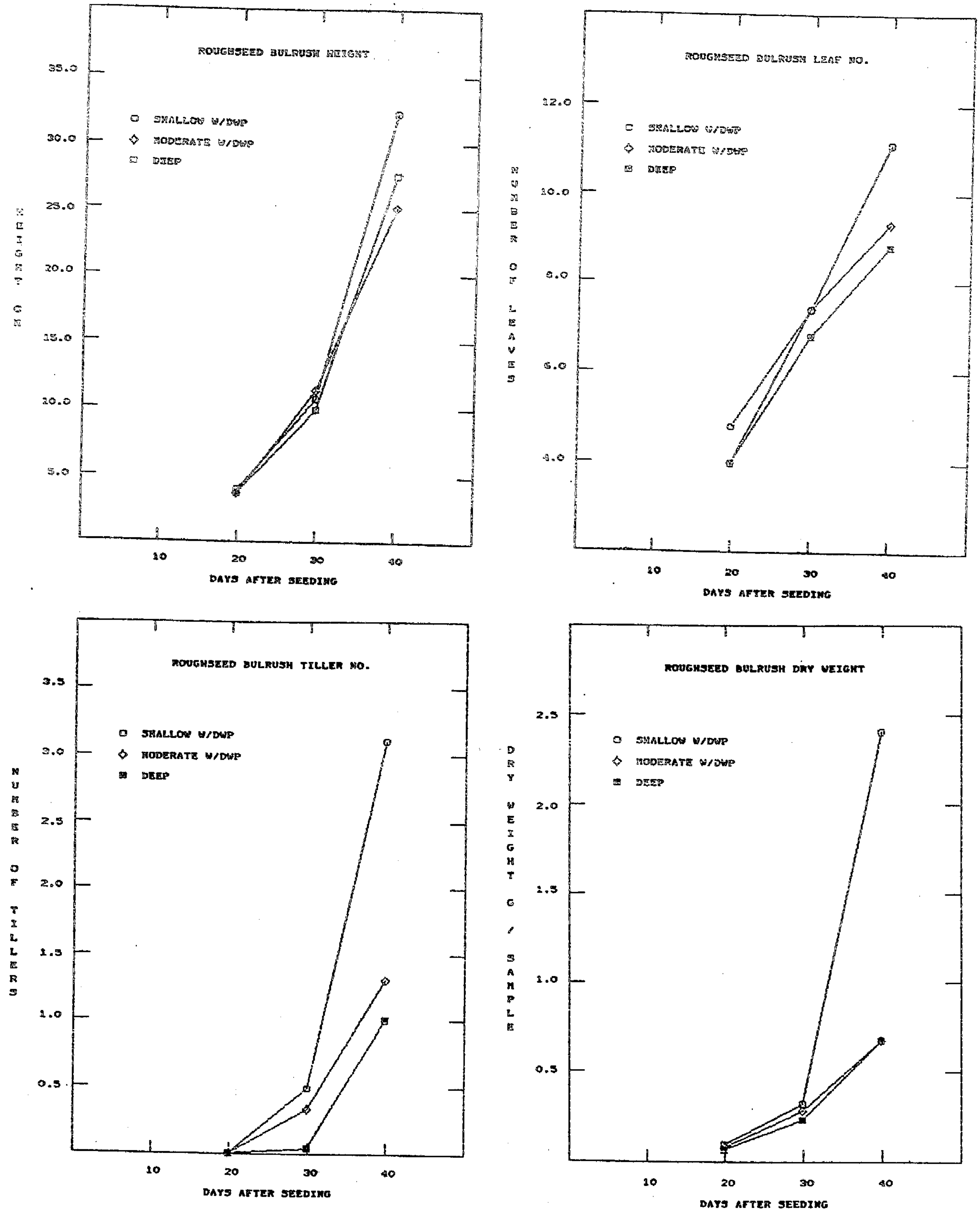
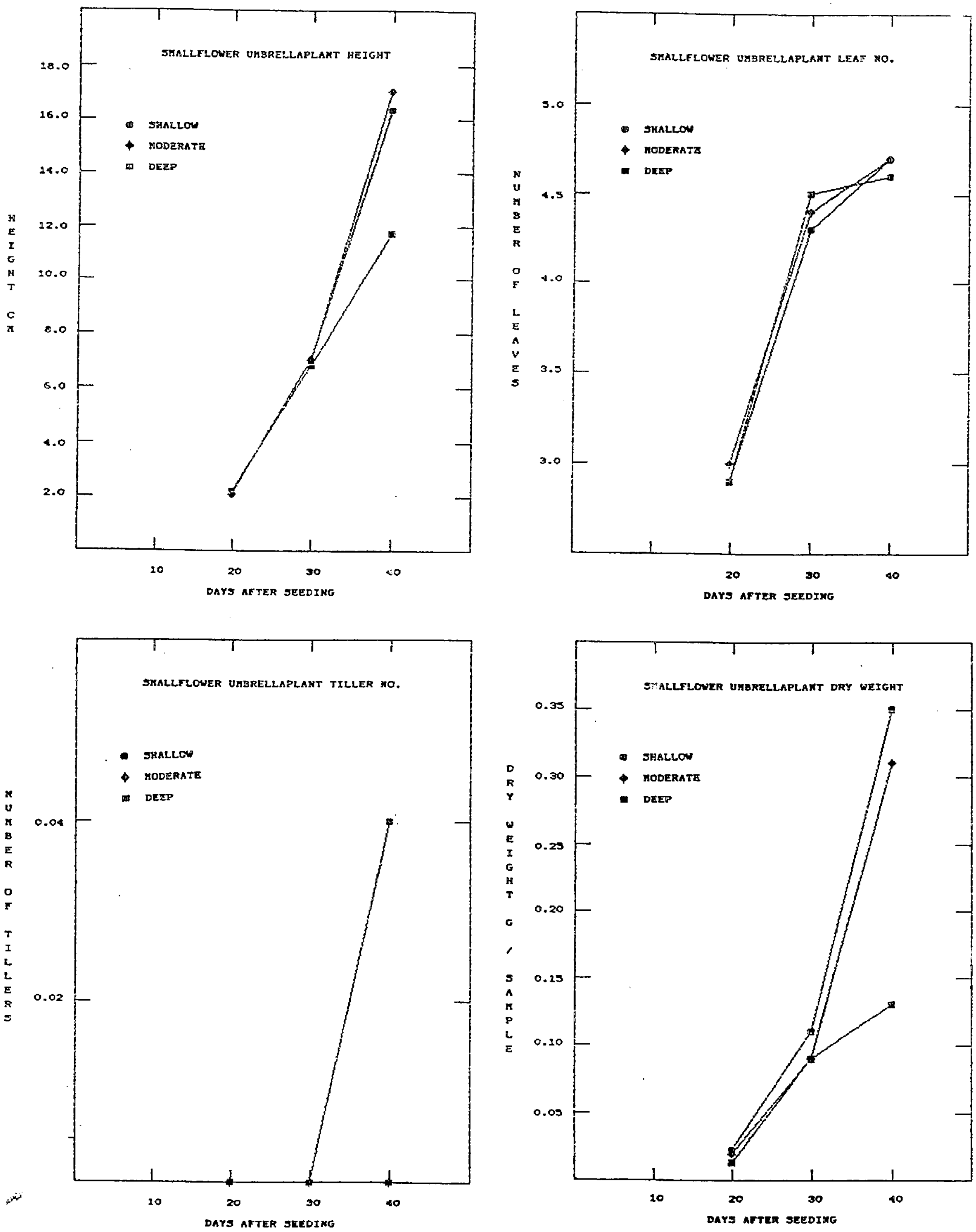


Figure 12. THE EFFECT OF WATER DEPTH ON ROUGHSEED BULRUSH GROWTH.


SMALLFLOWER UMBRELLAPLANT HEIGHT

SMALLFLOWER UMBRELLAPLANT LEAF NO.

SMALLFLOWER UMBRELLAPLANT TILLER NO.

SMALLFLOWER UMBRELLAPLANT DRY WEIGHT

Figure 13. THE EFFECT OF WATER DEPTH ON SMALLFLOWER UMBRELLAPLANT GROWTH.

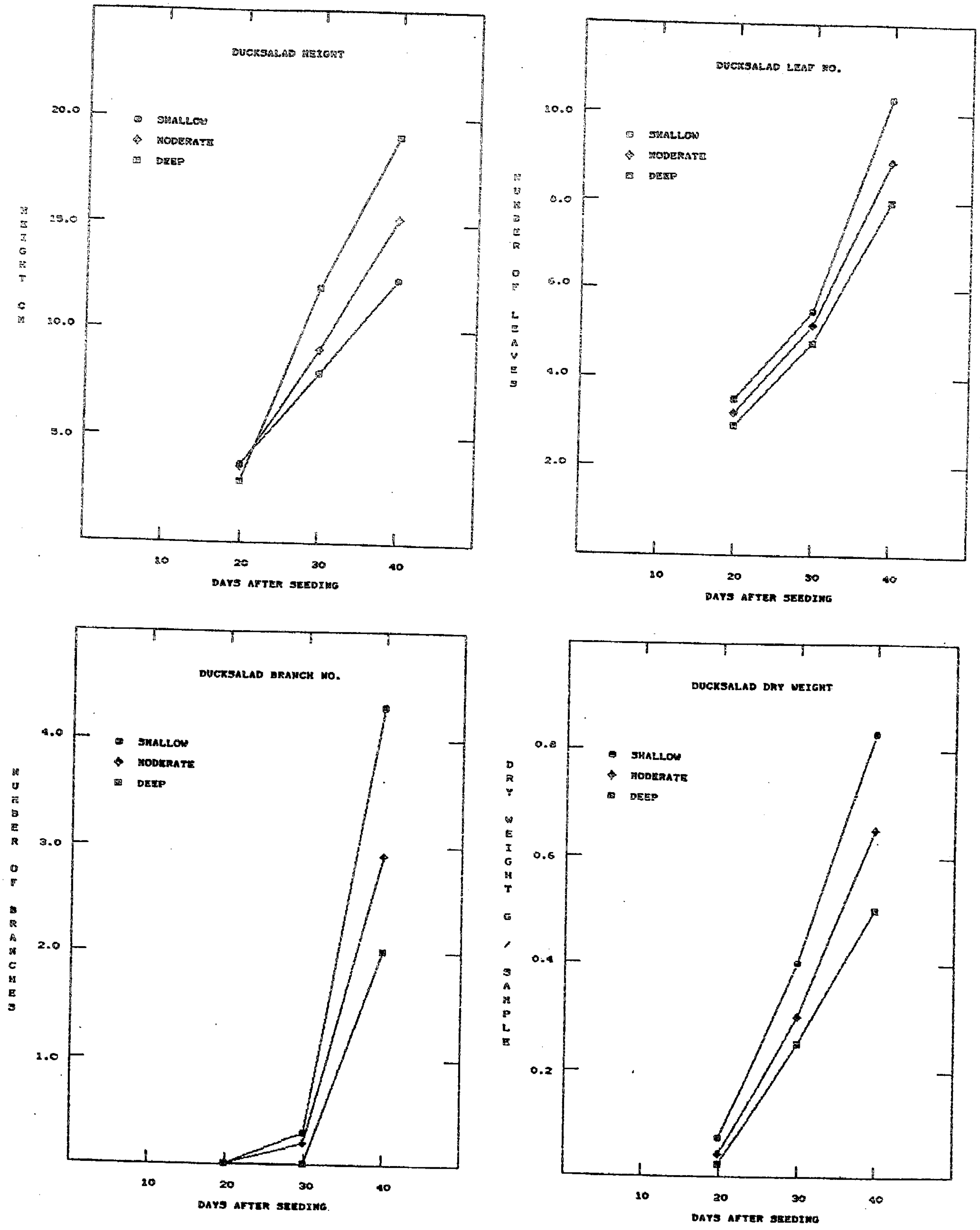


Figure 14. THE EFFECT OF WATER DEPTH ON DUCKSALAD GROWTH.

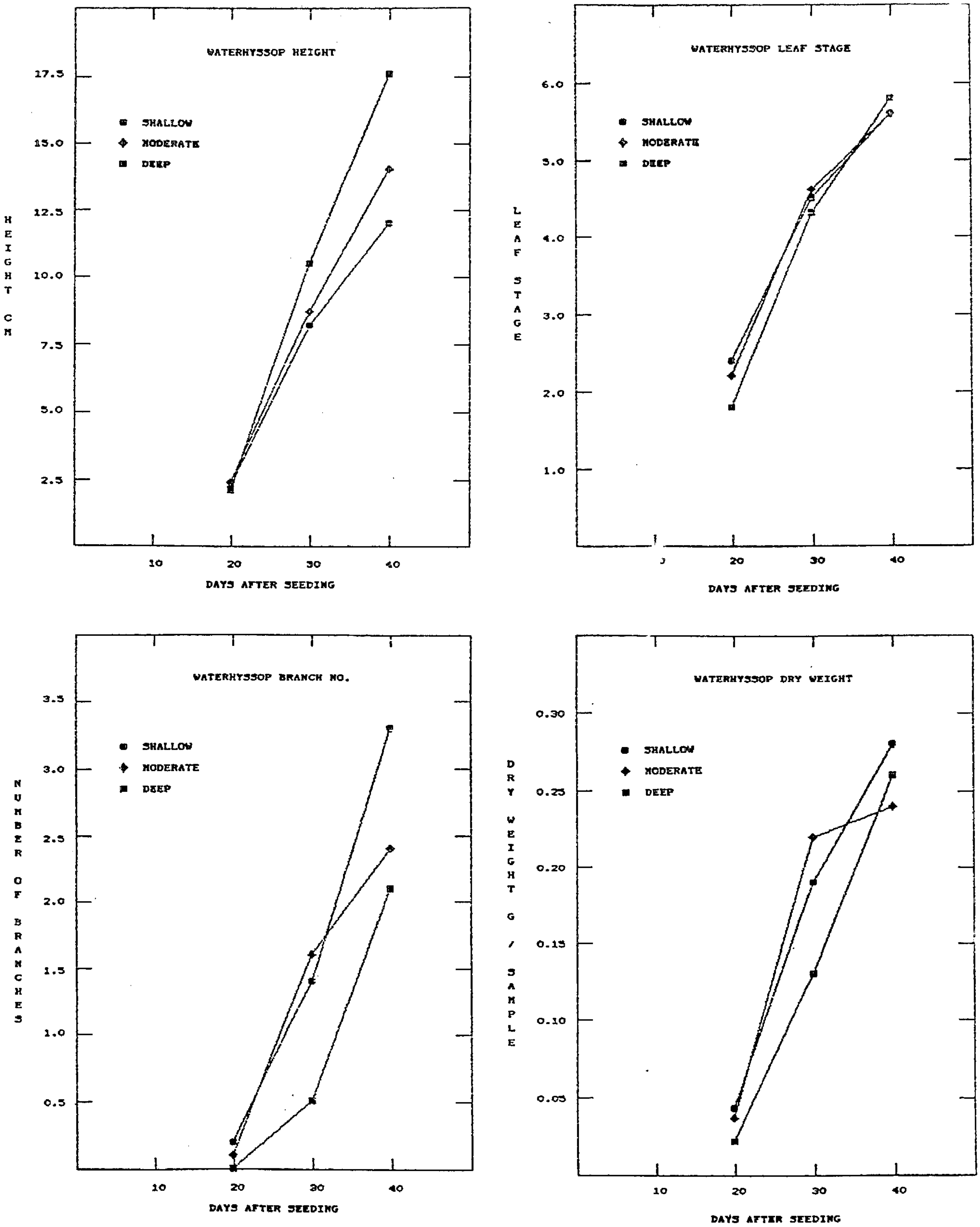


Figure 15. THE EFFECT OF WATER DEPTH ON WATERHYSSOP GROWTH.

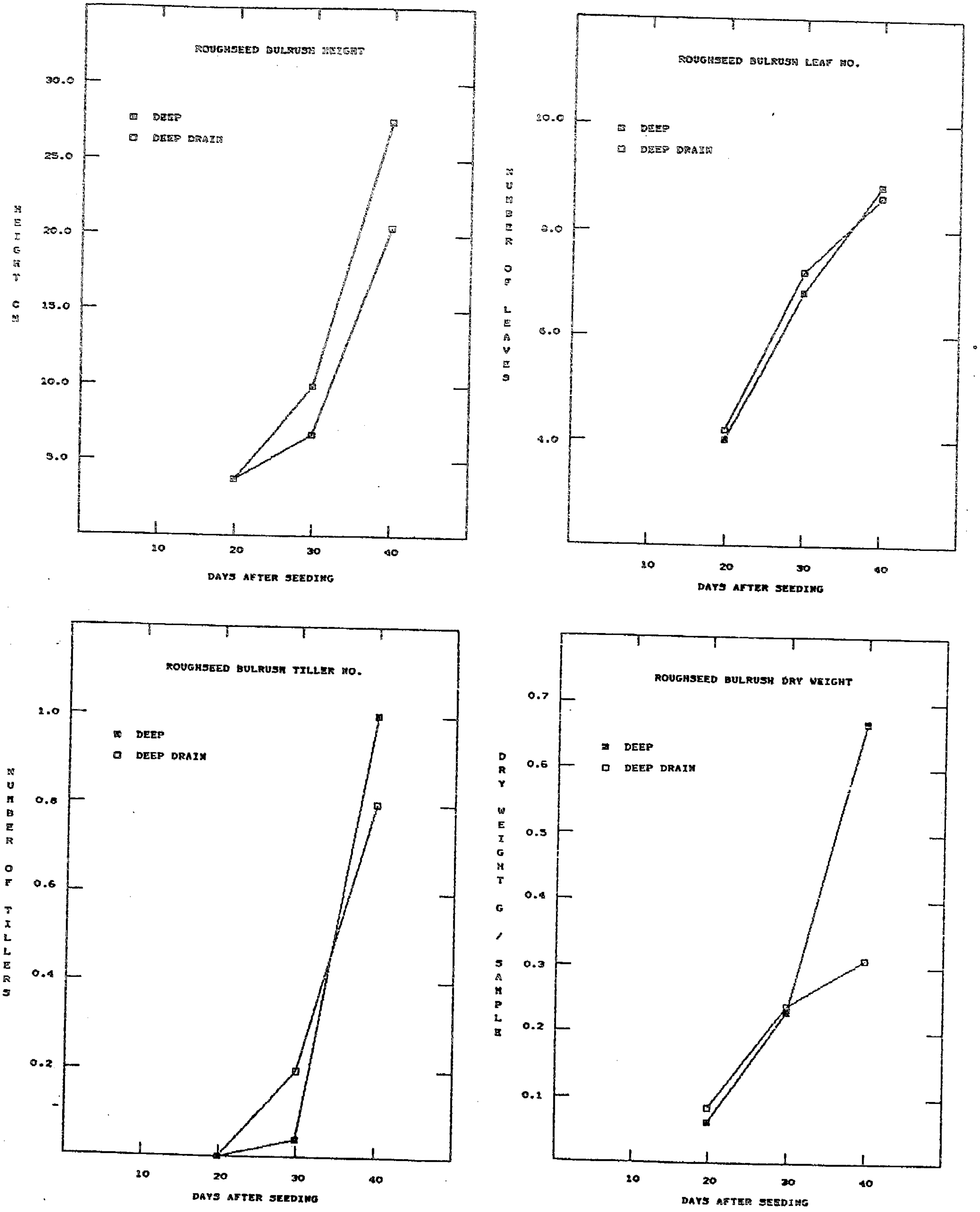


Figure 16. THE EFFECT OF CONTINUOUS VS. DISCONTINUOUS FLOODING ON ROUGHSEED BULRUSH GROWTH.

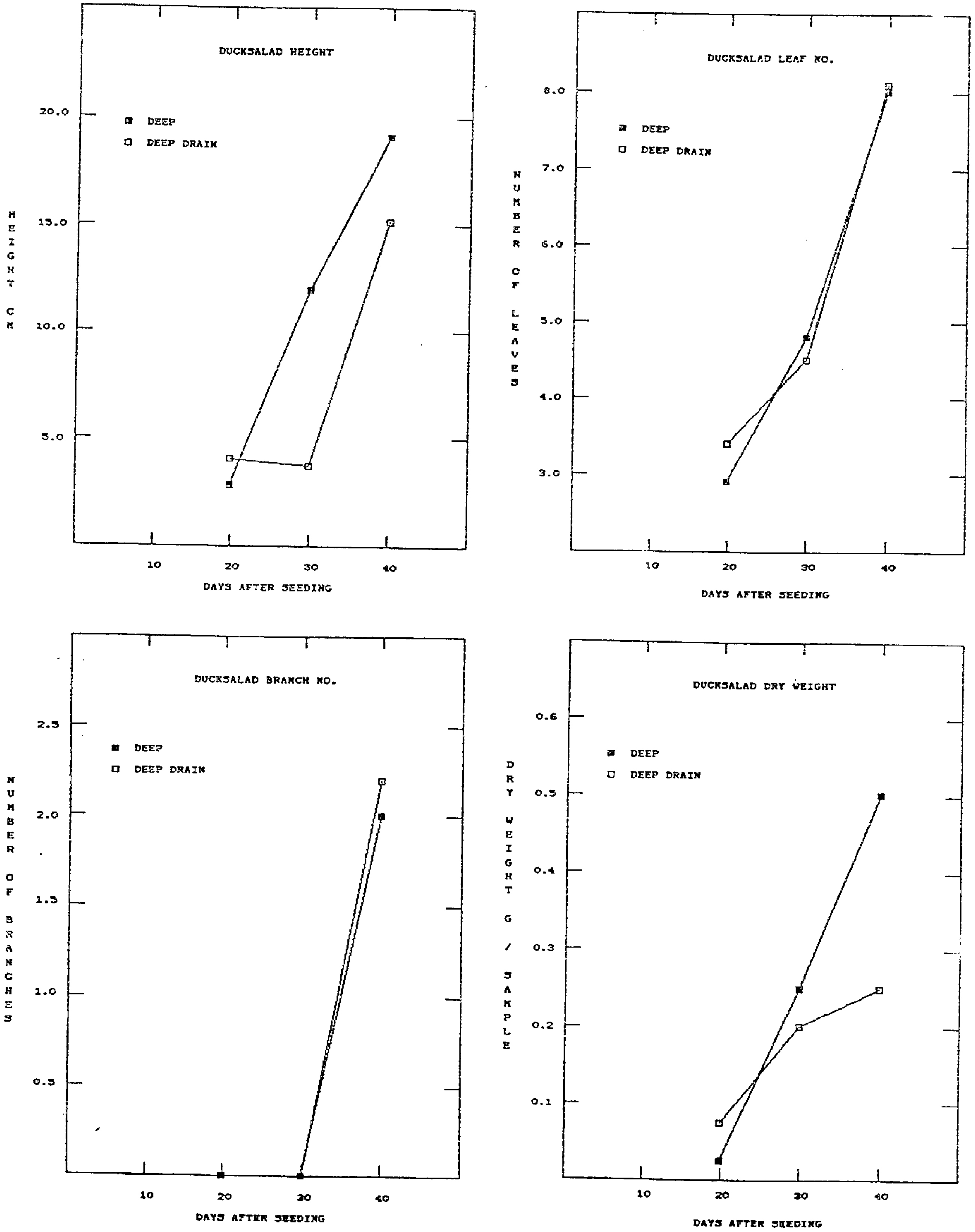


Figure 17. THE EFFECT OF CONTINUOUS VS. DISCONTINUOUS FLOODING ON DUCKSALAD GROWTH.

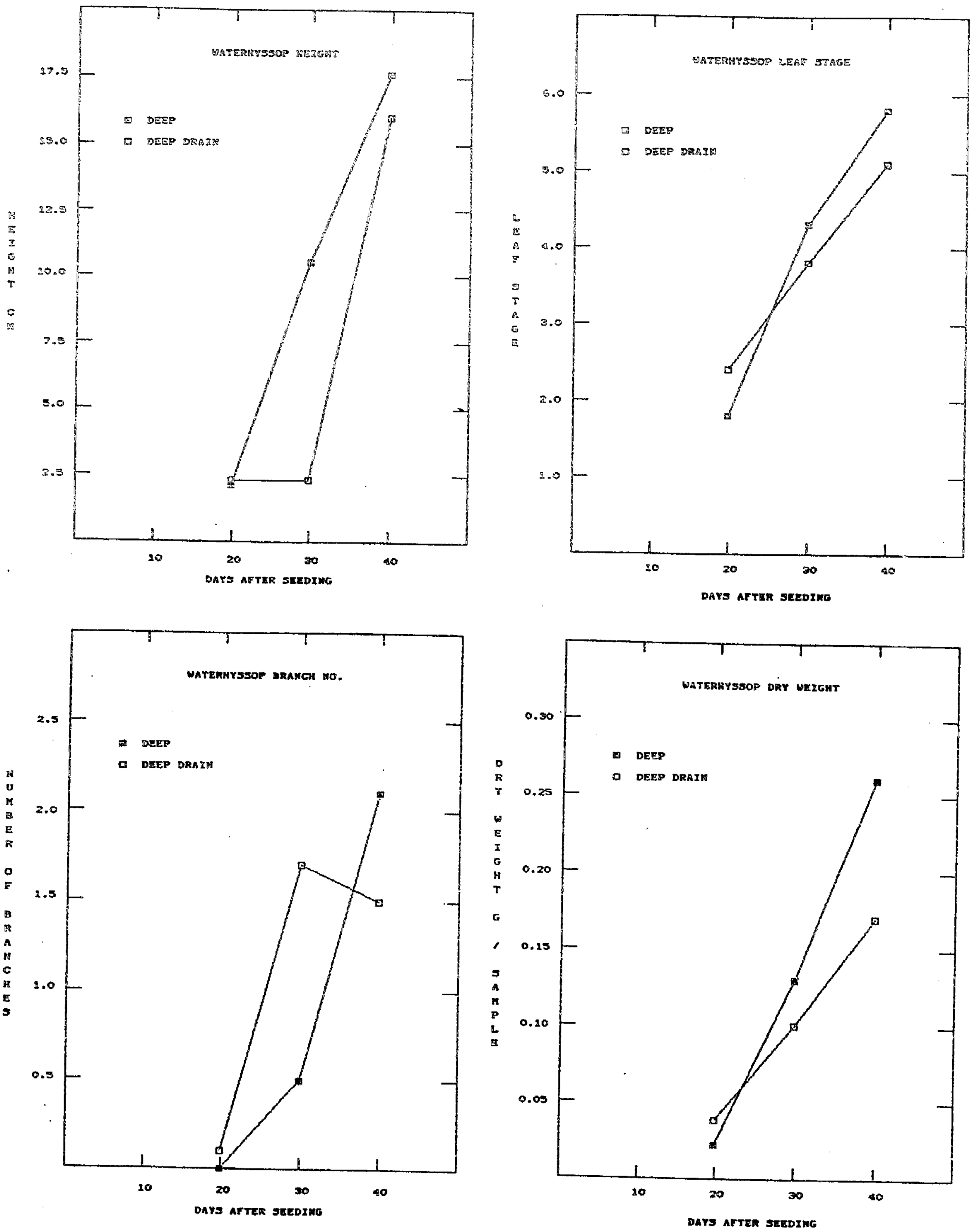


Figure 18. THE EFFECT OF CONTINUOUS VS. DISCONTINUOUS FLOODING ON WATERHYSSOP GROWTH.

Table 11. WEED CONTROL RATINGS BY SPECIES AND TREATMENT.

TREATMENT	WEED CONTROL RATING (6-27)[1]					RATING (8-2)	
	RSBR	SFUP	DS	WH	BYG[2]	RSBR	BYG
1	3.5	7.0	5.3	9.7	9.2	3.8	7.8
2	7.3	9.2	6.3	9.2	7.3	7.5	6.5
3	8.2	10.0	9.2	9.7	9.8	7.3	9.2
4	9.0	9.3	8.3	9.7	9.3	8.3	9.3
5	8.2	10.0	8.0	9.8	9.7	8.0	9.8
6	6.7	10.0	8.7	9.7	10.0	6.5	9.7
7	7.3	10.0	8.8	9.7	9.7	6.8	9.3
8	9.3	10.0	6.3	8.2	7.3	6.8	8.0
C.V. (%)	14.8	7.9	9.4	4.9	7.6	18.8	13.8
Among Treatments	**[3]	**	**	*	*	*	*
Among 2, 4, 5			**		**		**
Linear 2, 4, 5			*		**		**
Residual 2, 4, 5			*		**		
Among 1, 3, 5	**	**	**			**	
Linear 1, 3, 5	**	**	**			**	
Residual 1, 3, 5	**	*	**				
1,3 vs. 2, 4	**				*	**	
5 vs. 8			*	*	**		
Among 3, 6, 7							
Linear 3, 6, 7							
Residual 3, 6, 7							

---

[1] Weed control was rated on a scale of 1-10 with 1 = no control and 10 = excellent control.

[2] Weed abbreviations are as follows: RSBR = roughseed bulrush; SFUP = smallflower umbrellaplant; DS = ducksalad; WH = waterhyssop; and BYG = barnyardgrass (watergrass).

[3] Level of significance: *($P \geq .95$); **($P \geq .99$); ***($P \geq .999$).

Diseases

Inoculum levels for Sclerotium oryzae (stem rot) and S. oryzae sativae (aggregate sheath spot) were very low indicating low disease pressure. In 1985, water management treatments had no significant effect on stem rot or aggregate sheath spot disease severity (Table 12). Seed rot and seedling disease tended to be more prevalent with decreasing water depth, but this difference was not significant.

Table 12. EFFECT OF WATER MANAGEMENT ON SEVERITY OF STEM ROT AND AGGREGATE SHEATH SPOT (AGSS).

TREATMENT NO.	DISEASE RATING	
	STEM ROT[1>]	AGSS[2>]
1	1.0	2.2
2	1.1	1.2
3	1.0	3.0
4	1.1	1.7
5	1.3	4.7
6	1.0	4.4
7	1.1	4.3
8	1.5	3.7
	N.S.[3>]	N.S.

[1>] Disease index: 1 = healthy; 5 = severe.

[2>] Disease index: height of disease on 100 tillers (cm)/100, each value is a mean of 3 replicates.

[3>] N.S. = not significant.

Mosquitoes

General monitoring results showed the native populations of Culex tarsalis and Anopheles freeboni to be nonexistant in all treatments sampled. Relative development and survival rate studies showed that Culex tarsalis larvae developed faster in treatment 8 (deep drain) than other continuously flooded treatments (Table 13) and slower in treatment 2. Treatment 5 (deep) also developed faster. They also showed that survivorship was similar in all treatments.

Of the macroinvertebrates collected on July 1 there seems to be a greater diversity of organisms in treatment 8 but no difference in the total number of organisms.

Table 13. DEVELOPMENT AND SURVIVAL OF CULEX TARSALIS LARVAE IN SENTINEL BUCKETS[1].

TREATMENT	# SURVIVE[2]	PROPORTION PER INSTAR				
		I	II	III	IV	P
6/27/85						
2	11.8 ± 3.3	0.02	0.89	0.09	0	0
4	12.0 ± 4.8	0	0.87	0.13	0	0
5	15.5 ± 3.7	0.03	0.87	0.10	0	0
8	11.0 ± 4.2	0	0.05	0.95	0	0
6/28/85						
2	13.5 ± 4.6	0	0.83	0.17	0	0
4	16.0 ± 4.1	0	0.55	0.45	0	0
5	12.3 ± 7.4	0	0.62	0.38	0	0
8	16.0 ± 0.0	0	0	1.0	0	0
7/1/85						
2	12.2 ± 7.3	0	0.19	0.65	0.16	0
4	5.0 ± 7.1	0	0.70	0.30	0	0
5	13.3 ± 3.2	0	0.05	0.83	0.12	0
8	13.5 ± 6.4	0	0	0	1.0	0
7/2/85						
2	9.3 ± 6.1	0	0.19	0.68	0.13	0
4	9.5 ± 6.4	0	0	0.47	0.53	0
5	12.7 ± 4.5	0	0	0.75	0.25	0
8	13.5 ± 9.2	0	0	0	1.0	0
7/3/85						
2	9.3 ± 9.0	0	0	0.44	0.55	0
4	16.0 ± 1.4	0	0.14	0.39	0.47	0
5	18.0 ± 1.4	0	0	0.44	0.56	0
8	6.0 ± 7.1	0	0	0	1.0	0
7/5/85						
2	9.5 ± 9.3	0	0.02	0.29	0.69	0
4	8.3 ± 9.4	0	0	0.27	0.69	0.04
5	12.3 ± 4.9	0	0	0.04	0.96	0
8	18.5 ± 2.1	0	0	0	0.89	0.11

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[1] Twenty first instar *Culex tarsalis* larvae were placed in each bucket and buckets were placed in the field on June 25, 1985.

[2] Mean ±s.d. (range)

Rice Growth and Yield

Rice plant population counts by treatment are shown in table 14. Even though there are a few significant differences among treatments for a given sampling date, no consistant trend is evident over all the sampling dates. At 40 days after seeding (DAS) all treatments had adequate population levels (range 20-26 plants/sq.ft.) to maximize yield.

The effect of water management on early season rice growth and development, as measured by plant height, leaf stage, tiller production and plant dry weight accumulation, is shown in figures 19 and 20 and Appendix VII. Rice height increased significantly with increasing water depth, while leaf stage and tiller number decreased significantly. Biomass production (dry weight) decreased significantly in a few cases with increasing depth but was not consistent. Complete drainage of water (for 10 days between 20 and 30 DAS) affected rice growth in a number of ways. During the drain period (treatment 8) rice produced new leaves and tillers, but did not grow in height. This is in contrast to rice grown under continuous flood (treatment 5) which continued to increase in height. After the drain period rice in treatment 8 caught up in height, but then lagged significantly in tiller and biomass production. Length of water holding had no effect on rice height, leaf stage, tiller number or biomass production (Appendix VII).

The early season differences in tiller number due to water depth and drainage mostly disappeared as the season progressed. Table 15 shows that after heading (129 DAS) no significant differences in the number of fertile tillers per plant were observed. Panicle counts (Table 15), however, show that the deep drain (#8) and deep water (#5) treatments had significantly fewer panicles per square foot than the shallow water (#2) treatment. No other panicle differences were observed.

Table 16 shows the effect of water management practices on heading, height at maturity, lodging, grain moisture and yield. Early season shallow water delayed heading 5-6 days, increased moisture by 4 to 7% and decreased yield by 800 to 1000 lbs. per acre compared to the deep water treatment. The deep drain treatment had little or no effect on heading or moisture but did reduce yield by nearly 900 lbs. per acre compared to deep water. At maturity water depth or drainage had no effect on height or lodging. The early season height differences among the various water depth treatments disappeared following panicle initiation when water levels in all treatments were equalized at 7 inches. Length of water holding period had no effect on heading, height, lodging, moisture or yield.

Table 14. RICE PLANT POPULATION COUNTS DURING THE SEEDLING AND EARLY TILLERING STAGES.

TREATMENT	RICE PLANT POPULATION AT DAYS AFTER SEEDING		
	20	30	40
1	27.2	26.0	20.9
2	30.3	29.7	26.0
3	25.2	27.2	20.7
4	24.9	24.9	20.4
5	26.0	21.8	20.1
6	32.4	32.1	24.1
7	27.0	26.5	21.7
8	29.6	33.1	21.4
C.V. (%)	11.5	12.8	10.7
Amoung Treatments	N.S.[1]	*[2]	N.S.
Among 2, 4, 5		*	*
Linear 2, 4, 5		*	**
Residual 2, 4, 5			
Among 1, 3, 5			
Linear 1, 3, 5			
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8		**	
Among 3, 6, 7	*		
Linear 3, 6, 7			
Residual 3, 6, 7	*		

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[1] N.S. = not significant

[2] Level of significance: *(P≥.95) and **(P≥.99).

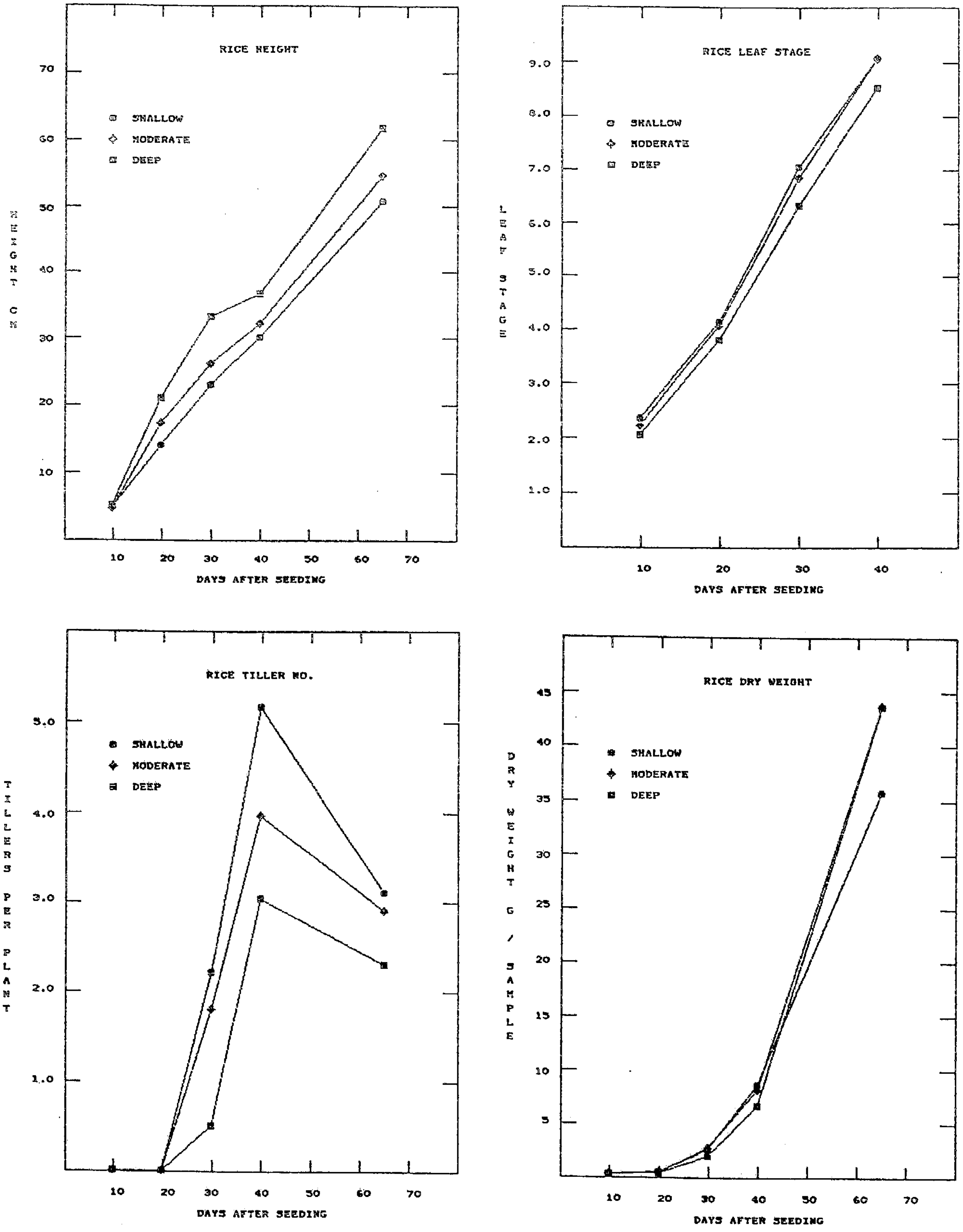

Figure 19. THE EFFECT OF WATER DEPTH ON RICE GROWTH.

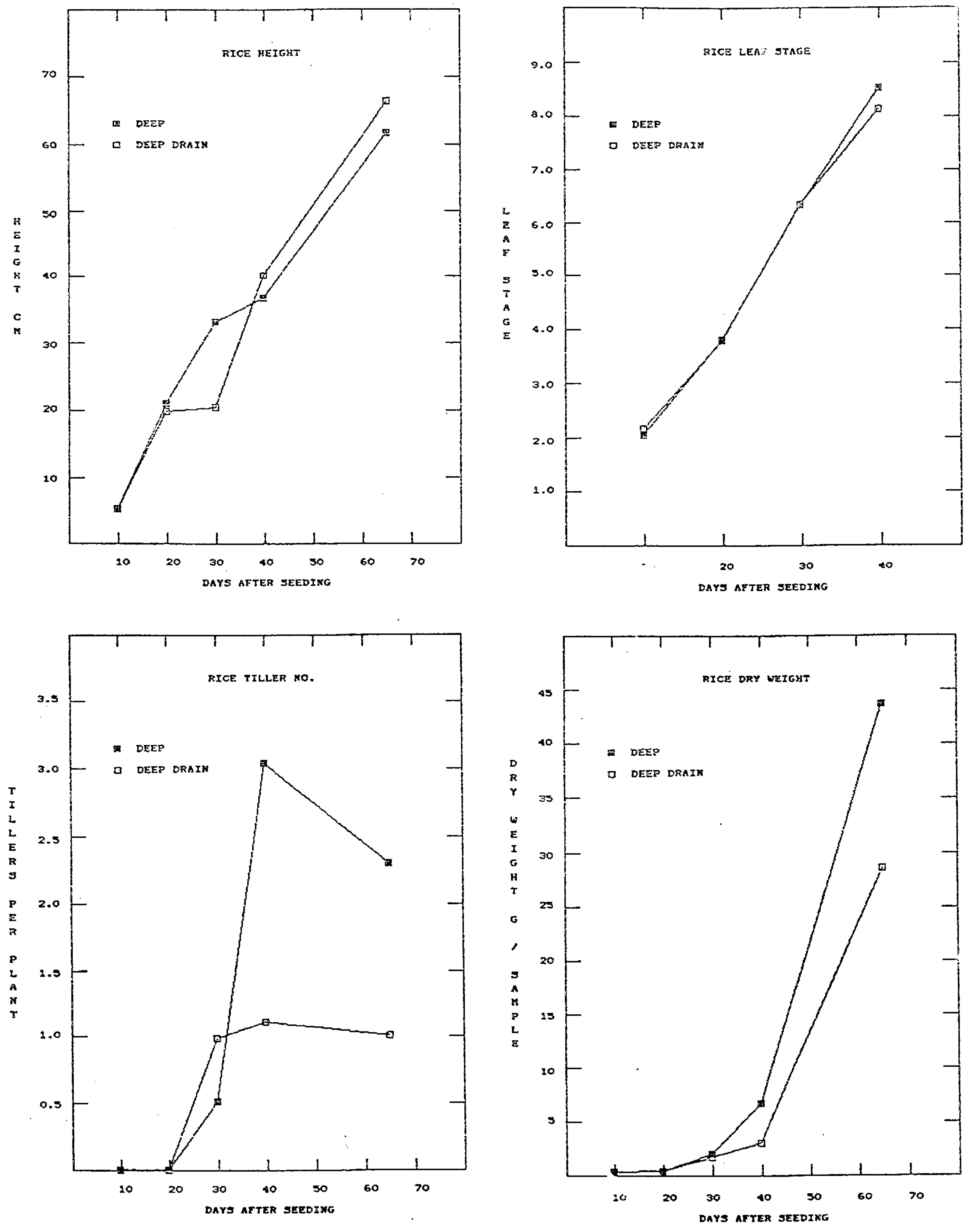

Figure 20. THE EFFECT OF CONTINUOUS VS. DISCONTINUOUS FLOODING ON RICE GROWTH.

Table 15. ESTIMATED NUMBER OF FERTILE TILLERS PER RICE PLANT BASED ON PANICLE AND PLANT POPULATION DENSITY.

TREATMENT	PLANTS/ FT^2 [1]	PANICLE/ FT^2 [2]	FERTILE TILLERS/ PLANT [3]
1	20.9	64.9	3.1
2	26.0	78.2	3.1
3	20.7	71.2	3.5
4	20.4	76.1	3.7
5	20.1	62.7	3.3
6	24.1	74.4	3.1
7	21.7	67.1	3.1
8	21.1	57.6	2.7
C.V. (%)	10.7	12.6	18.6
Among Treatments	N.S. [4]	N.S.	N.S.
Among 2, 4, 5	* [5]		
Linear 2, 4, 5	**	*	
Residual 2, 4, 5			
Among 1, 3, 5			
Linear 1, 3, 5			
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8			
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

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[1] Plants per square foot based on a 40 DAS sampling date.

[2] Panicles per square foot counted on September 3 (129 DAS).

[3] Fertile tillers per plant is an estimate calculated from the number of panicles/ft^2 divided by the number of plants/ft^2 at 40 DAS.

[4] N.S. = not significant

[5] Level of significance: *($P \geq .95$) and **($P \geq .99$).

Table 16. THE EFFECT OF WATER MANAGEMENT ON THE AGRONOMIC CHARACTERISTICS AND YIELD OF RICE.

TREATMENT	DAYS TO 50% HEADING	MATURE PLANT HEIGHT (CM)	% LODGING (1-99)[1]	% GRAIN MOISTURE @ HARVEST	YIELD (LB/A) @ 14% MOISTURE
1	109	97.7	1.0	28.0	9100
2	110	91.0	1.0	31.2	9330
3	104	92.7	10.0	23.1	10030
4	106	96.0	1.0	27.7	10940
5	104	92.7	1.3	23.7	10160
6	106	91.0	1.7	23.2	9770
7	104	97.7	1.0	23.3	10320
8	103	94.0	1.0	22.7	9280
C.V. (%)	1.7	4.5	242.0	18.5	10.2
Among Treatments	**[2]	N.S.[3]	N.S.	N.S.	N.S.
Among 2, 4, 5	**			*	*
Linear 2, 4, 5	**			*	
Residual 2, 4, 5					*
Among 1, 3, 5	**				
Linear 1, 3, 5	**				
Residual 1, 3, 5			*		
1, 3 vs. 2, 4					
5 vs. 8					
Among 3, 6, 7					
Linear 3, 6, 7					
Residual 3, 6, 7					

---

[1] Lodging was rated at harvest from 1-99 with 1 = 0% lodging and 99 = 100% lodging.

[2] Level of significance: *($P \geq .95$) and **($P \geq .99$).

[3] N.S. = not significant

DISCUSSION

Field Parameters

The linear trends of decreasing minimum water temperature and increasing maximum water temperature with decreasing water depth during the first half of the season were highly significant in almost every case. Even though the analyses show that the temperature and depth relationship is linear it does not mean that it is exactly a straight line. Even when the residual, which is the deviation from the straight line, is fairly small, the relationship could be curvilinear. With only three points (depths) it is difficult to determine the exact relationship.

Molinate Dissipation and Discharge

The results show the calculated half-life (t1/2) for molinate to be between 3.5 to 4.1 days, which is similar to the 2.8 to 3.8 days calculated from our 1984 studies. Possible reasons for the difference between years are the higher wind velocity and greater data varibility in 1984 compared to 1985.

Of the water management practices studied (water depth, water-holding period and continous flood vs. drainage) the only factor that affected the dissipation of molinate was water depth. During the WHP molinate dissipation increased with decreasing water depth. Table 8 and Figure 5 compare the half-lives and dissipation curves of treatments 2, 4 and 5 that had the same WHP (8 days) but were maintained at different depths. If we assume that at high molinate concentrations the main route of dissipation is volatilization, the dissipation theory can be expressed as:

$$Ct = Co \exp - (t \cdot k/d)$$

Where: t = time
Ct = concentration of solute at time t
Co = initial concentration of solute
K = a constant for a given chemical
d = depth of water

The volatization rate term, K/d, would increase with decreasing depth and vice versa. This theory is quanitatively consistent with the data if we assume the water depths for treatments 2 (1-3 in.), 4 (3-5 in) and 5 (5-7 in.) were 3.0, 3.9 and 5.0, respectively. The correlation between theory and measured field water depths appears only qualitative given measurements were actually 3.2, 4.7 and 6.4 inches, respectively. It appears that as the molinate concentration declines that other routes of dissipation, possibly soil adsorption, become increasely important.

Since the differences in molinate concentrations at different water depths disappeared as residue levels declined and before the end of the WHP, this phenomenon is of no real practical significance in reducing molinate discharges into state water.

Molinate dissipation curves from treatments 1, 3, 5 and 8 (Figure 3) which had the same water depth during the WHP (5-7 in.) and the same WHP (8 days) but different amounts of water released and different depths after the WHP were very similar. This is consistant with non linear soil adsorption at low concentrations. These treatments basically compare the effect of releasing or draining different amounts of water from plots after the WHP. The results show that water management practices following an 8 day or longer WHP has little or no effect on the dissipation of molinate, but as we will discuss can effect the discharge of molinate.

The molinate dissipation curves and calculated half-lives from treatments 3, 6 and 7 (Figure 4 and Table 7) which had the same water depths during and after the WHP (3-5 in.) but had different WHPs (8, 16 and 32 days, respectively) showed only minor differences. Again this is consistant with non linear soil adsorption at low molinate concentrations. These treatments basically compare the effect of releasing or draining water at different times. Once again, the length of the WHP has little effect on the dissipation of molinate. But as we will discuss, WHP can have a major effect on herbicide discharge into state waters.

The greater persistance of molinate when applied preflood and incorporated into the soil may also be explained by a greater level of soil adsorption.

Net discharge of molinate in rice irrigation drain water is largely related to the concentration of molinate at the time of release and amount of water released. Since time (water holding period) had the greatest effect on reducing molinate concentrations, WHPs appear to be the best way to reduce the net discharge of molinate. At any given WHP, minimizing the amount of drain water released also greatly reduced the net discharge of molinate.

In general, the peak discharge rate (g/day) for each treatment was a considerable portion of the total net discharge of molinate (ie. a good portion of the net discharge occurred on a given day, usually on the first day after the WHP). This was when the concentration was the highest and when the most water was released.

Treatments 1 and 8 resulted in the highest net discharge as well as the highest peak discharge rates. These treatments had relatively short WHPs (8 day) and had large volumes of water released immediately after the WHP. Treatments 3, 4 and 5 had peak and net discharges of an intermediate level. All were 8 day WHP with low volumes of water released. This demonstrates the relative importance of the amount of water released. Treatments 2, 6 and 7 had the lowest peak and net discharges. Among these treatments the peak and net discharges declined with longer WHPs.

The relatively low concentration of molinate in rice irrigation water following a preflood incorporated application is especially noteworthy. The residue levels following the preflood applicaiton were substantially lower than those following a postflood application. The day 3 residue level from the preflood treatment was comparable to the day 16 level from the postflood treatment. In light of these findings, _if_ the efficiacy of this method of application is adequate, then the method should be encouraged as a partial replacement for postflood applications. This is a large if, however, since earlier studies have indicated that this method may not provide consistent weed control. Further studies should be conducted to confirm the apparent lower residue status of this method and to compare the efficacy of these two methods. These findings also indicate that an 8 day WHP is probably not necessary for the preflood method.

Molinate concentration fluctuations in water appeared to be the result of increased soil adsorption/desorption oscillations (Figure 10) as temperature rose. However the fluxes in the soil were too small (by at least an order of magnitude) to account for the changes in the water. Uneven distribution of molinate in the water is an unlikely explanation since a rhodamine test indicated that the water was well-mixed.

Although the samples were taken at 2-3 hour intervals the data indicate that the oscillations might be even more frequent, so greater time resolution would be required to quantify the phenomenon accurately.

Pest Growth and Damage

Weeds

The trends for a lower weed population in the deep drain treatment (#8) and higher populations in the shallow water treatments (#1 or #2) were similar to the 1984 study. Broadleaf populations in the long water holding period treatments (#6 and #7) were not different from the shorter holding period treatment (#3) in 1985 in contrast to 1984. Because of this inconsistancy from year to year and the highly variable populations, there is some uncertainty about these trends.

Broadleaf and sedge weed growth was suppressed by deep water and stimulated by shallow water. The shallow water grown weeds, which were more vigorous, were generally not controlled as well as those grown in deep water. Although watergrass growth was not monitored, control of this weed was poorer in continuous shallow water (treatment 2). Even though the effect of drainage on weed growth appeared somewhat transient for most species it did result in poorer weed control of several species (DS, WH, RSBR and BYG). Similar trends were observed in 1984. Since length of water holding period had no effect on weed growth, weed control in the long WHP treatments was not significantly different from that in the short water holding treatment. These results demonstrate the adverse effects of shallow water and drainage on weed control and the beneficial effects of moderate or deep water in suppressing broadleaf weeds and watergrass.

Even though shallow water encouraged vigorous early season rice growth it also stimulated weed growth and resulted in poorer weed control and lower rice yields.

Invertebrates

In 1984 there was a trend toward an increasing number of midge larvae with increasing water depth but it was not significant. No other invertebrate pests were present in significant numbers. Because of the limited populations of invertebrate pests in 1984, monitoring was discontinued in 1985.

Diseases

Stem rot and aggregate sheath spot (AGSS) diseases were not a factor in this years' study. Inoculum levels and severity ratings were extremely low to nonexistent. In 1984, AGSS was significantly less severe in treatment 8, where water was drained after the WHP. Treatments (1-7) that were continuously flooded throughout the season developed varying levels of AGSS, all significantly higher than where water was drained. It would be necessary to continue monitoring inoculmn levels and disease severity over several more years to determine the long term effects of drainage and continuous flood on this disease.

The non-significant trend of increasing seed rot and seedling disease with decreasing water depth should be investigated further.

Mosquitoes

The more rapid mosquito larval development (Culex tarsalis) in treatment 8 (deep drain) and 5 (deep) and slower development in treatment 2 (shallow water) was similar to our 1984 results. Shallow water seems to present some unfavorable environment for larval development. A possible explanation for this difference in developmental rate might be the lower minimum water temperature associated with shallow water. This can not be confirmed since no measurement was taken within the sentinel buckets. Other possible explanations include differences in nutrient levels or differences in the diversity of macroinvertebrates. No confirmation of higher nutrient levels have been established to date.

No relationship between water depth and native larval populations of Culex tarsalis or Anopheles freeborni was observed in 1984. In addition, all treatments were negative for both species in 1985.

Rice Growth and Yield

Early season differences in rice growth due to water depth disappeared for the most part by maturity. At the end of the season no significant difference in height or the number of tillers per plant were observed. Even though shallow water encouraged rapid early season rice growth it delayed heading and maturity compared to deep water. This is probably related to the water temperature profiles associated with shallow and deep water. Shallow water had lower minimums and higher maximums compared to deep water. These results were similar to 1984. Differences in early season rice growth due to drainage also disappeared for the most part by maturity. Height and the number of tillers per plant in deep drain plots were not significantly different from continuous deep water plants at or near maturity. Even though tiller numbers were not significantly different, plants subjected to the drain period did have fewer tillers per plant.

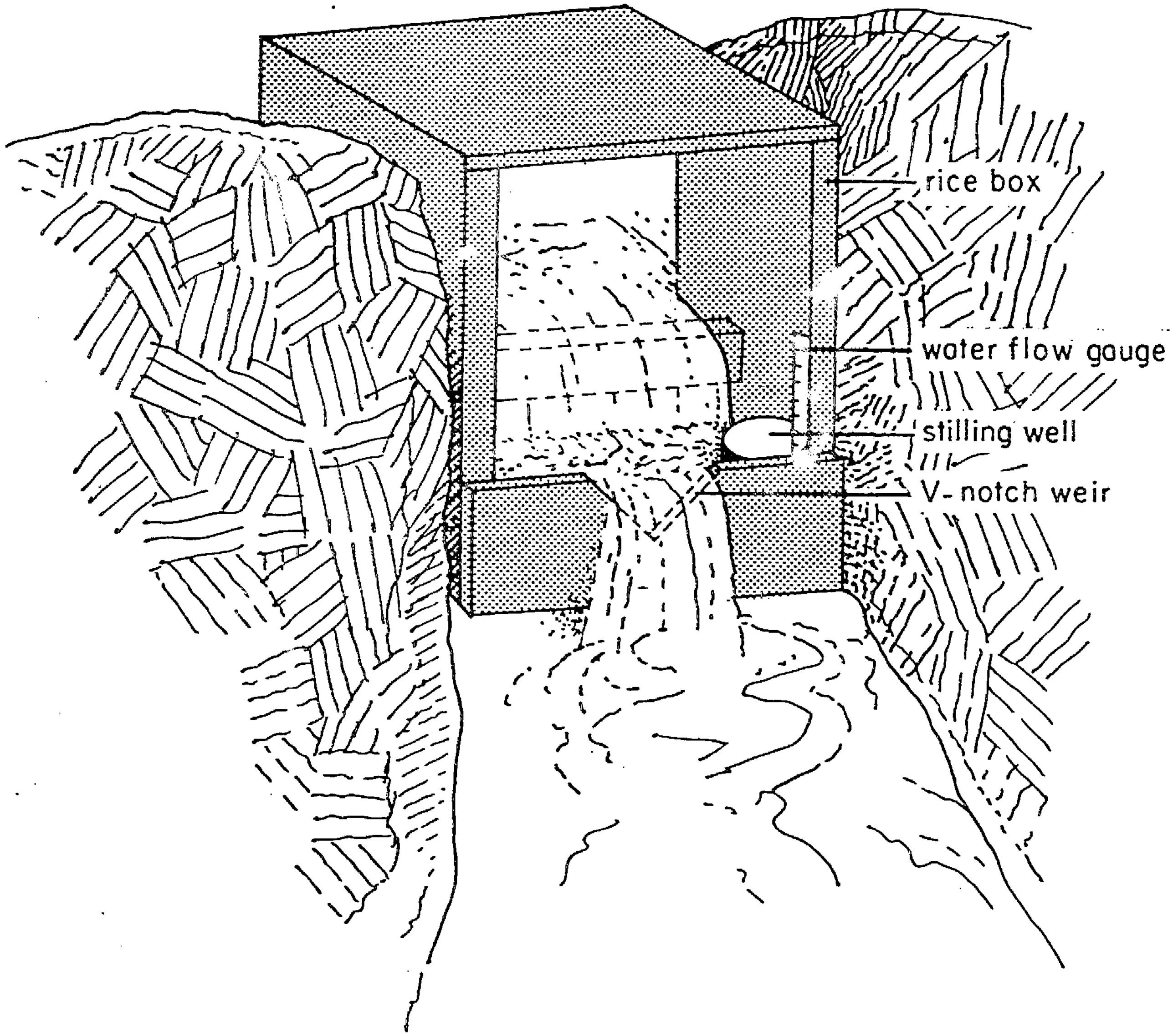
Although length of water holding period had no significant adverse effect on rice growth and development in this study there are potential production problems that could cause adverse effects during a water holding period. Problems with salinity, toxic organic acids and gases or algae all could adversely affect rice and preclude water holding for long periods. In the absence of production problems, however, this study demonstrates that it is possible to hold water for long periods (up to 32 days). More intensive management is required during a WHP to maintain desired water depths.

Shallow water encouraged early season rice growth, but also encouraged weed growth, resulting in depressed rice yields. Deep water suppressed weed growth but slowed rice growth somewhat. A moderate water depth (4-5 in.) provided a "happy medium" for rice growth and weed suppression and resulted in the highest yield. Draining water for 10 days between 20 and 30 DAS adversely affected early season rice growth, gave poorer control of some weeds and reduced yield. Water holding period had no effect on yield in this experiment.

The first year of this study (1984) was generally plagued by large variations in nitrogen fertility as a result of nitrogen immobilization and other N losses. These variations made the 1984 yield results much more difficult to interpret than those described above. In 1984 no significant differences in yield were observed. Nonetheless, the shallow water treatment yields were not depressed as they were in 1985 primarily because weed control was better (two broadleaf herbicide applications). Additionally, yields in the 1984 long water holding treatments were the most affected by nitrogen deficiency and variability.

APPENDIX I.

RICE WEIR OUTLET BOX RETRO-FITTED WITH A 90° V-NOTCH WEIR FOR WATER FLOW MEASUREMENT



APPENDIX II.

COMPARISIONS BETWEEN WATER FLOW MEASUREMENT METHODS

CORRELATION ANALYSIS

Factors Compared	Correlation Coefficients by Plot Number								
	9	11	13	15	10	12	14	16	Mean
Recorder vs. Manual (AM)	.94	.96	.77	.93	.89	.78	.91	.75	.87
Recorder vs. Manual (PM)	.96	.91	.87	.98	.90	.82	.90	.85	.90
Recorder vs. Manual Average (AM and PM)	.96	.98	.93	.98	.98	.88	.94	.93	.95

REGRESSION ANALYSIS

Factors Compared	R-Squared Values by Plot Number								
(y) (X)	9	11	13	15	10	12	14	16	Mean
Recorder vs. Manual (AM)	.89	.92	.59	.86	.79	.61	.82	.57	.76
Recorder vs. Manual (PM)	.92	.84	.75	.95	.81	.67	.82	.72	.81
Recorder vs. Manual Average (AM and PM)	.92	.96	.87	.96	.96	.78	.88	.86	.90

APPENDIX III.

SOIL ANALYSIS [1>]

PLOT NO.	SP (%)	pHs	ECe (milli-mhos/cm)	Mg (me/l)	Ca (me/l)	Na (me/l) (est)	ESP (%) (est)	P (ppm)	K (ppm)	ZN (ppm)
1	50	6.3	0.51	1.2	0.5	3.4	4	4.4	210	3.5
2	53	6.5	1.00	0.9	0.6	8.5	12	5.6	185	3.9
3	52	6.2	0.45	0.9	0.6	3.0	3	3.7	180	3.2
4	48	6.4	0.81	1.0	0.6	6.5	8	3.5	165	2.7
5	49	5.9	0.40	1.2	0.5	2.3	2	5.4	165	3.6
6	50	5.9	0.56	1.5	0.7	3.4	3	5.7	175	2.9
7	49	5.8	0.35	1.4	0.7	1.4	1	3.4	180	4.3
8	48	5.8	0.48	1.5	1.0	2.3	2	3.6	180	3.6
9	45	5.7	0.29	0.9	0.7	1.3	1	3.3	160	2.9
10	49	5.3	0.52	1.7	1.2	2.3	2	12.2	210	4.8
11	45	5.4	0.28	1.4	0.5	0.9	<1	7.5	145	2.6
12	48	5.2	0.40	1.4	1.0	1.6	1	6.8	200	3.9
13	42	5.3	0.30	1.2	0.6	1.2	<1	6.8	145	2.2
14	46	5.1	0.52	1.6	1.4	2.2	2	10.3	200	3.3
15	44	5.2	0.34	1.5	0.7	1.2	<1	8.3	160	2.4
16	47	5.1	0.41	1.5	1.0	1.6	<1	10.1	190	2.7
17	43	5.0	0.33	1.4	0.6	1.3	<1	9.5	180	2.7
18	44	5.1	0.55	1.8	1.2	2.5	2	10.2	210	3.2
19	44	5.1	0.30	1.2	0.6	1.2	<1	9.4	180	2.8
20	47	4.9	0.50	1.4	1.5	2.1	2	10.4	210	3.2
21	44	4.9	0.35	2.0	0.9	0.6	<1	10.4	190	3.3
22	43	5.1	0.52	1.7	1.3	2.2	2	12.1	200	2.8
23	41	5.0	0.29	1.1	0.6	1.2	<1	12.7	185	3.2
24	46	5.1	0.54	1.7	1.3	2.4	2	9.3	190	2.9
1 A	46	6.0	0.27	1.0	0.8	0.9	<1	5.0	165	2.7
2 A	47	5.6	0.45	1.3	1.2	2.0	2	8.9	190	3.8
3 A	42	5.2	0.25	0.8	0.6	1.1	<1	9.9	180	2.6
4 A	49	5.2	0.51	1.7	1.2	2.2	2	12.3	220	2.9

[1>] Soil sampled on April 10, 1984.

APPENDIX IV.

MEASURED TREATMENT WATER DEPTHS DURING THE FIRST HALF OF THE RICE SEASON

TREATMENT	MEAN WATER DEPTH (FEET) BY TIME PERIOD [1>]				
	1	2	3	4	5
1	0.25	0.49	0.24	0.24	0.24
2	0.30	0.27	0.29	0.28	0.29
3	0.42	0.48	0.41	0.41	0.41
4	0.42	0.39	0.41	0.42	0.40
5	0.57	0.53	0.57	0.56	0.55
6	0.44	0.50	0.42	0.41	0.39
7	0.41	0.50	0.43	0.42	0.41
8	0.57	0.51	0.01	0.44	0.56

[1>] Time periods and conditions were as follows: (1) 4-27 to 5-6, free water surface with water spilling, rice at 0-2 leaf stage; (2) 5-7 to 5-16, free water surface with water being held, rice at 2-4 leaf stage; (3) 5-17 to 5-25, crop canopy at about 10-30%, water drained, spilling or being held, rice at 4 leaf stage to early tillering; (4) 5-26 ot 6-10, crop canopy about 30-60%, water spilling or being held, rice at early to mid-tillering; and (5) 6-11 to 7-5, crop canopy at about 60-90%, water spilling, rice at mid-tillering to panicle initiation.

APPENDIX V.

MEASURED TREATMENT WATER FLOW RATES DURING THE FIRST HALF OF THE RICE SEASON

TREATMENT	MEAN WATER FLOW RATE (ACRE FEET/WEEK) BY TIME PERIOD[1]				
	1	2	3	4	5
1	0.028	0.017	0.018	0.016	0.020
2	0.021	0.011	0.016	0.014	0.022
3	0.018	0.003	0.020	0.034	0.019
4	0.015	0.010	0.019	0.027	0.018
5	0.020	0.001	0.020	0.029	0.019
6	0.020	0.0	0.011	0.030	0.016
7	0.024	0.0	0.001	0.008	0.018
8	0.019	0.015	0.021	0.025	0.017

[1] Time periods and conditions were as follows: (1) 4-27 to 5-6, free water surface with water spilling, rice at 0-2 leaf stage; (2) 5-7 to 5-16, free water surface with water being held, rice at 2-4 leaf stage; (3) 5-17 to 5-25, crop canopy at about 10-30%, water drained, spilling or being held, rice at 4 leaf stage to early tillering; (4) 5-26 ot 6-10, crop canopy about 30-60%, water spilling or being held, rice at early to mid-tillering; and (5) 6-11 to 7-5, crop canopy at about 60-90%, water spilling, rice at mid-tillering to panicle initiation.

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	ROUGHSEED BULRUSH HEIGHT (CM) AT DAYS AFTER PLANTING		
	20	30	40
1	3.9	10.7	32.1
2	3.3	10.4	27.8
3	3.6	11.4	25.0
4	3.3	10.1	28.8
5	3.7	9.9	27.5
6	4.1	10.8	29.3
7	3.9	10.2	25.8
8	3.7	6.7	20.5
C.V. (%)	41.5	68.2	51.9
Treatments	N.S.	N.S.	N.S.
Among 2, 4, 5			
Linear 2, 4, 5			
Residual 2, 4, 5			
Among 1, 3, 5			
Linear 1, 3, 5			
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8		*	*
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	ROUGHSEED BULRUSH LEAF NO. AT DAYS AFTER PLANTING		
	20	30	40
1	4.8	7.4	11.1
2	3.7	7.2	9.7
3	4.0	7.4	9.3
4	3.6	7.1	10.1
5	4.0	6.8	8.8
6	4.2	7.5	9.8
7	4.1	7.2	9.6
8	4.2	7.2	8.6
C.V. (%)	38.5	16.1	34.0
Treatments	N.S.	N.S.	N.S.
Among 2, 4, 5			
Linear 2, 4, 5			
Residual 2, 4, 5			
Among 1, 3, 5			*
Linear 1, 3, 5	*	*	**
Residual 1, 3, 5			
1, 3 vs. 2, 4		**	
5 vs. 8			
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	ROUGHSEED BULRUSH TILLER NO. AT DAYS AFTER PLANTING		
	20	30	40
1	0	0.49	3.1
2	0	0.36	1.7
3	0	0.33	1.3
4	0	0.22	2.1
5	0	0.04	1.0
6	0	0.51	1.8
7	0	0.20	1.6
8	0	0.20	0.8
C.V. (%)	-	272.0	194.0
Treatments	-	N.S.	N.S.
Among 2, 4, 5			
Linear 2, 4, 5			
Residual 2, 4, 5			
Among 1, 3, 5			*
Linear 1, 3, 5		*	**
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8			
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

	ROUGHSEED BULRUSH DRY WT. (G/SAMPLE) AT DAYS AFTER PLANTING		
TREATMENT	20	30	40
1	0.091	0.32	2.40
2	0.063	0.24	1.11
3	0.076	0.28	0.67
4	0.063	0.23	1.06
5	0.062	0.23	0.67
6	0.076	0.31	0.94
7	0.079	0.25	0.79
8	0.084	0.24	0.31
C.V. (%)	24.3	25.5	68.6
Treatments	N.S.	N.S.	N.S.
Among 2, 4, 5			
Linear 2, 4, 5			
Residual 2, 4, 5			
Among 1, 3, 5			*
Linear 1, 3, 5			**
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8			
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	SMALLFLOWER UMBRELLAPLANT HEIGHT (CM) AT DAYS AFTER PLANTING		
	20	30	40
1	2.5	8.5	17.3
2	2.1	7.0	16.3
3	2.1	7.8	12.2
4	2.1	7.0	17.0
5	2.2	6.8	11.7
6	2.8	8.3	16.9
7	2.1	6.7	13.7
8	2.7	6.3	12.2
C.V. (%)	54.1	75.9	71.8
Treatments	N.S.	N.S.	N.S.
Among 2, 4, 5			
Linear 2, 4, 5			
Residual 2, 4, 5			
Among 1, 3, 5			*
Linear 1, 3, 5			*
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8			
Among 3, 6, 7	*		
Linear 3, 6, 7			
Residual 3, 6, 7	**		

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

	SMALLFLOWER UMBRELLAPLANT LEAF NO. AT DAYS AFTER PLANTING		
TREATMENT	20	30	40
1	3.1	4.5	5.3
2	2.9	4.3	4.7
3	3.1	4.4	4.3
4	3.0	4.4	4.7
5	2.9	4.5	4.6
6	3.3	4.4	4.9
7	3.0	4.4	4.7
8	3.2	5.4	4.8
C.V. (%)	31.0	30.1	33.9
Treatments	N.S.	*	N.S.
Among 2, 4, 5			
Linear 2, 4, 5			
Residual 2, 4, 5			
Among 1, 3, 5			*
Linear 1, 3, 5			
Residual 1, 3, 5			*
1, 3 vs. 2, 4			
5 vs. 8		**	
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	SMALLFLOWER UMBRELLAPLANT TILLER NO. AT DAYS AFTER PLANTING 20	30	40
1	0	0.0	0.18
2	0	0.0	0.04
3	0	0.0	0.0
4	0	0.0	0.0
5	0	0.0	0.0
6	0	0.0	0.02
7	0	0.0	0.0
8	0	0.11	0.11
C.V. (%)	-	1004.0	687.1
Treatments	-	*	N.S.
Among 2, 4, 5			
Linear 2, 4, 5			
Residual 2, 4, 5			
Among 1, 3, 5			*
Linear 1, 3, 5			*
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8		**	
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	SMALLFLOWER UMBRELLAPLANT DRY WT (G/SAMPLE) AT DAYS AFTER PLANTING 20	30	40
1	0.020	0.16	0.32
2	0.023	0.11	0.35
3	0.017	0.10	0.12
4	0.020	0.09	0.31
5	0.013	0.09	0.13
6	0.035	0.11	0.28
7	0.020	0.09	0.21
8	0.024	0.21	0.21
C.V. (%)	32.0	44.4	54.8
Treatments	N.S.	N.S.	N.S.
Among 2, 4, 5			
Linear 2, 4, 5			
Residual 2, 4, 5			
Among 1, 3, 5			
Linear 1, 3, 5			
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8		*	
Among 3, 6, 7	*		
Linear 3, 6, 7			
Residual 3, 6, 7	**		

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	DUCKSALAD HEIGHT (CM) AT DAYS AFTER PLANTING 20	30	40
1	3.6	8.9	14.5
2	3.6	7.8	12.3
3	3.6	11.3	14.9
4	3.5	8.9	15.1
5	2.8	11.9	19.1
6	3.5	10.1	14.9
7	3.2	8.4	16.8
8	4.0	3.7	15.1
C.V. (%)	46.8	34.4	62.9
Treatments	N.S.	**	N.S.
Among 2, 4, 5		**	*
Linear 2, 4, 5		**	**
Residual 2, 4, 5			
Among 1, 3, 5		**	
Linear 1, 3, 5		**	*
Residual 1, 3, 5			
1, 3 vs. 2, 4		**	
5 vs. 8	*	**	
Among 3, 6, 7		**	
Linear 3, 6, 7		**	
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

	DUCKSALAD LEAF NO. AT DAYS AFTER PLANTING		
TREATMENT	20	30	40
1	3.4	5.6	9.5
2	3.5	5.5	10.3
3	3.4	5.4	8.8
4	3.2	5.2	8.9
5	2.9	4.8	8.0
6	3.2	5.0	9.0
7	2.9	4.6	8.3
8	3.4	4.5	8.1
C.V. (%)	27.9	31.6	52.9
Treatments	*	*	N.S.
Among 2, 4, 5	*		
Linear 2, 4, 5	**		*
Residual 2, 4, 5			
Among 1, 3, 5	*		
Linear 1, 3, 5	*	*	
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8	*		
Among 3, 6, 7			
Linear 3, 6, 7		*	
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	DUCKSALAD BRANCH NO. AT DAYS AFTER PLANTING 20	30	40
1	0	0.49	3.5
2	0	0.33	4.3
3	0	0.27	2.8
4	0	0.18	2.9
5	0	0.04	2.0
6	0	0.09	3.1
7	0	0.07	2.3
8	0	0.0	2.2
C.V. (%)	-	344.8	159.0
Treatments	-	*	N.S.
Among 2, 4, 5			
Linear 2, 4, 5		*	*
Residual 2, 4, 5			
Among 1, 3, 5		*	
Linear 1, 3, 5		**	
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8			
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

	DUCKSALAD DRY WT. (G/SAMPLE) AT DAYS AFTER PLANTING		
TREATMENT	20	30	40
1	0.064	0.50	0.79
2	0.074	0.40	0.83
3	0.060	0.46	0.69
4	0.042	0.30	0.65
5	0.024	0.25	0.50
6	0.063	0.28	0.78
7	0.037	0.22	0.66
8	0.073	0.20	0.26
C.V. (%)	38.1	15.8	64.0
Treatments	N.S.	N.S.	N.S.
Among 2, 4, 5	*		
Linear 2, 4, 5	*		
Residual 2, 4, 5			
Among 1, 3, 5			
Linear 1, 3, 5	*		
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8	*		
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	WATERHYSSOP HEIGHT (CM) AT DAYS AFTER PLANTING 20	30	40
1	2.9	9.3	11.9
2	2.3	8.2	12.0
3	2.6	10.5	18.3
4	2.4	8.7	14.0
5	2.2	10.6	17.7
6	2.7	9.8	19.1
7	2.5	10.8	18.6
8	2.4	2.3	16.0
C.V. (%)	36.8	62.6	74.9
Treatments	*	**	*
Among 2, 4, 5			
Linear 2, 4, 5			*
Residual 2, 4, 5			
Among 1, 3, 5	**		*
Linear 1, 3, 5	**		*
Residual 1, 3, 5			
1, 3 vs. 2, 4	**		
5 vs. 8		**	
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	WATERHYSSOP LEAF STAGE AT DAYS AFTER PLANTING 20	30	40
1	2.4	4.4	5.3
2	2.4	4.5	5.6
3	2.3	4.5	6.0
4	2.2	4.6	5.6
5	1.8	4.3	5.8
6	2.3	4.6	6.0
7	2.1	4.5	5.9
8	2.4	3.8	5.1
C.V. (%)	40.1	33.4	22.1
Treatments	N.S.	N.S.	*
Among 2, 4, 5	*		
Linear 2, 4, 5	**		
Residual 2, 4, 5			
Among 1, 3, 5	*		
Linear 1, 3, 5	**		
Residual 1, 3, 5			
1, 3 vs. 2, 4			
5 vs. 8	*		*
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	WATERHYSSOP BRANCH NO. AT DAYS AFTER PLANTING		
	20	30	40
1	0.04	2.2	2.7
2	0.18	1.4	3.3
3	0.16	1.4	4.8
4	0.11	1.6	2.4
5	0.0	0.5	2.1
6	0.07	1.0	4.4
7	0.07	0.9	3.7
8	0.09	1.7	1.5
C.V. (%)	382.0	130.0	122.0
Treatments	N.S.	*	*
Among 2, 4, 5		*	
Linear 2, 4, 5		*	
Residual 2, 4, 5		*	
Among 1, 3, 5		**	*
Linear 1, 3, 5		**	
Residual 1, 3, 5			**
1, 3 vs. 2, 4			
5 vs. 8		**	
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VI.

THE EFFECT OF WATER MANAGEMENT ON WEED GROWTH

TREATMENT	WATERHYSSOP DRY WT. (G/SAMPLE) AT DAYS AFTER PLANTING		
	20	30	40
1	0.061	0.23	0.21
2	0.043	0.19	0.28
3	0.050	0.29	0.60
4	0.037	0.22	0.24
5	0.022	0.13	0.26
6	0.047	0.19	0.50
7	0.039	0.22	0.50
8	0.038	0.10	0.17
C.V. (%)	27.5	32.6	51.1
Treatments	*	N.S.	N.S.
Among 2, 4, 5			
Linear 2, 4, 5	*		
Residual 2, 4, 5			
Among 1, 3, 5	**	*	*
Linear 1, 3, 5	**		
Residual 1, 3, 5		*	*
1, 3 vs. 2, 4	*		
5 vs. 8			
Among 3, 6, 7			
Linear 3, 6, 7			
Residual 3, 6, 7			

APPENDIX VII.

THE EFFECT OF WATER MANAGEMENT ON RICE GROWTH

	RICE HEIGHT (CM) AT DAYS AFTER SEEDING				
TREATMENT	10	20	30	40	65
1	4.6	20.2	23.0	29.2	54.4
2	4.9	14.0	22.9	30.1	50.6
3	5.2	19.8	27.9	31.4	57.9
4	4.7	17.2	26.1	32.2	54.5
5	5.1	21.0	33.2	36.7	61.7
6	5.0	20.7	26.8	31.5	55.3
7	4.9	21.4	28.4	31.9	56.9
8	5.3	19.7	20.3	40.1	66.4
C.V. (%)	34.6	36.4	26.5	29.7	26.6
Treatments	N.S.	**	**	**	**
Among 2, 4, 5		**	**	*	*
Linear 2, 4, 5		**	**	**	**
Residual 2, 4, 5					
Among 1, 3, 5			**	**	
Linear 1, 3, 5			**	**	*
Residual 1, 3, 5					
1, 3 vs. 2, 4		**			
5 vs. 8			**		
Among 3, 6, 7					
Linear 3, 6, 7					
Residual 3, 6, 7					

APPENDIX VII.

THE EFFECT OF WATER MANAGEMENT ON RICE GROWTH

TREATMENT	RICE LEAF STAGE AT DAYS AFTER PLANTING				
	10	20	30	40	65
1	2.2	4.0	6.8	8.9	--
2	2.3	4.1	7.0	9.1	--
3	2.3	3.9	6.7	7.9	--
4	2.2	4.1	6.8	9.1	--
5	2.0	3.8	6.3	8.5	--
6	2.3	4.0	6.7	8.2	--
7	2.2	4.0	6.8	8.8	--
8	2.2	3.8	6.3	8.1	--
C.V. (%)	19.1	15.7	10.6	25.9	--
Treatments	*	N.S.	**	N.S.	--
Among 2, 4, 5	*	*	**		
Linear 2, 4, 5	**	*	**		
Residual 2, 4, 5					
Among 1, 3, 5	*		*		
Linear 1, 3, 5	*		*		
Residual 1, 3, 5	*				
1, 3 vs. 2, 4					
5 vs. 8					
Among 3, 6, 7					
Linear 3, 6, 7					
Residual 3, 6, 7					

APPENDIX VII.

THE EFFECT OF WATER MANAGEMENT ON RICE GROWTH

TREATMENT	RICE TILLER NO. AT DAYS AFTER PLANTING				
	10	20	30	40	65
1	0	0	1.4	4.0	2.6
2	0	0	2.2	5.2	3.1
3	0	0	1.3	3.3	2.7
4	0	0	1.8	4.0	2.9
5	0	0	0.5	3.0	2.3
6	0	0	0.9	2.8	2.2
7	0	0	1.1	3.2	2.6
8	0	0	1.0	1.1	1.0
C.V. ($)	-	-	120.8	94.9	97.7
Treatments	-	-	**	**	*
Among 2, 4, 5			**	*	
Linear 2, 4, 5			**	**	
Residual 2, 4, 5					
Among 1, 3, 5			*		
Linear 1, 3, 5			*		
Residual 1, 3, 5					
1, 3, vs. 2, 4			**		
5 vs. 8				*	*
Among 3, 6, 7					
Linear 3, 6, 7					
Residual 3, 6, 7					

APPENDIX VII.

THE EFFECT OF WATER MANAGEMENT ON RICE GROWTH

TREATMENT	RICE DRY WT. (G/SAMPLE) AT DAYS AFTER PLANTING				
	10	20	30	40	65
1	0.36	0.46	2.47	6.65	33.7
2	0.37	0.54	2.66	8.58	35.7
3	0.36	0.42	2.44	6.20	46.5
4	0.36	0.50	2.77	8.09	43.7
5	0.35	0.40	1.97	6.60	43.6
6	0.36	0.46	1.90	5.84	34.4
7	0.36	0.42	2.18	5.88	44.4
8	0.34	0.41	1.72	3.04	28.6
C.V. (%)	3.5	10.9	18.1	24.5	26.1
Treatments	N.S.	*	N.S.	*	N.S.
Among 2, 4, 5		*			
Linear 2, 4, 5		**			
Residual 2, 4, 5					
Among 1, 3, 5					
Linear 1, 3, 5					
Residual 1, 3, 5					
1, 3 vs. 2, 4		*			
5 vs. 8				*	
Among 3, 6, 7					
Linear 3, 6, 7					
Residual 3, 6, 7					

APPENDIX J

MOLINATE AND THIOBENCARB CONCENTRATIONS IN SACRAMENTO VALLEY DRAINAGES: EFFECTS OF RICE TAIL-WATER RECYCLING

PREPARED BY:

J. W. Cornacchia 1/
B. L. Montoya 1/

R. S. Schnagl 2/
J. E. Kusick 2/

Pollutant Investigations Branch 1/
Division of Water Quality
State Water Resources Control Board

Agriculture Unit 2/
Central Valley Regional Water Quality Board

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SUMMARY

The concentrations of two rice herbicides, molinate and thiobencarb were monitored in a Sacramento Valley farm and a reclamation district tail-water recirculation system. In addition, the areal distribution of residues was investigated in drainages east of the Sacramento River and the Sacramento-San Joaquin Delta/Estuary. The Heidrick Farms recirculation study demonstrated that a sizable reduction in thiocarbamate levels in rice farm effluent can be achieved by recycling field tailwater. Molinate levels had decreased to 15 % (8.9 ug/L) of the measured peak value prior to release from the farm. Thiobencarb concentrations during the discharge ranged from 24 to 51 ug/L (18 and 39 % of the peak level). Partial drainwater recirculation within Reclamation District 108 coupled with longer field water holding periods reduced the peak concentrations of molinate and thiobencarb (95 and 18 ug/L respectively) and total mass emissions to the Sacramento River compared to 1982. Water sampling east of the Feather River identified two drainages which discharge thiocarbamate residues to the Feather River, Honcut Creek and Jack Slough. Spatial surveys within the lower Sacramento River and Sacramento-San Joaquin Delta/Estuary revealed that molinate originating from the Sacramento Valley, spread throughout the delta waterways. Residues carried into the lower Sacramento River entered the Cache Slough and Mokelumne River systems and the Suisun Bay estuary.

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RECOMMENDATIONS

The following recommendations are intended to further reduce the amount of rice herbicides discharged from individual farms and reclamation districts located in the Sacramento Valley through cost effective tail-water recirculation practices. Specific interagency-industry committees already exist to coordinate the development and implementation of tail-water recycling including the Rice Herbicide Working Group (CDFA) and the Sacramento Valley Water Quality Committee.

(1) Promote the expansion of farm tail-water recycling through a three part program which would:

(a) Develop and test new types of farm recycling-impoundment systems including the use of "set-aside" acreage. The immediate objective would be to implement systems which can retain tail-water for up to three or four weeks after an herbicide application;

(b) Perform limited water quality monitoring of new system prototypes to determine the minimum effective recirculation or impoundment period necessary to reduce rice herbicide levels to meet water quality guidelines recommended by the Department of Health Services and the Department of Fish and Game;

(c) Further promote the development and use of such systems by restricting a greater percentage of thiobencarb use to recycling systems.

(2) Promote the expansion of drain water recirculation within Sacramento Valley reclamation districts or other large rice growing areas. Steps which could be taken include:

(a) Identification of districts which have the potential, or present means to recirculate and impound drain water;

(b) Investigate cost-effective return flow management strategies for districts identified in 2(a) which would increase the residence time of rice field tail-water within those drainage systems. For example, irrigation deliveries could be reduced over a three to four week period as drain water recycling is practiced to meet irrigation demand;

(c) Investigate potential sources of funding to provide the necessary capital to construct recirculation facilities in areas identified in 2(a). Facility improvements could include conveyance and storage structures as well as surface water pumps.

INTRODUCTION

Recent environmental monitoring studies have shown that pesticides applied to Sacramento Valley rice fields during the spring are discharged to the Sacramento River through a series of agricultural drains and sloughs. Two aquatic herbicides in particular, molinate and thiobencarb, have been found in water, fish, and sediment collected during May and June from surface drains (Tanji et al., 1982; Finlayson et al., 1982). Seasonal losses of carp observed in the Colusa Basin Drain between 1981 and 1983 were likely caused by molinate (Finlayson and Lew, 1983a). The combined return flows from Colusa Basin Drain, Sacramento Slough, Reclamation District 108, and Butte Slough (at the Sacramento Slough outfall) produced detectable levels of molinate and thiobencarb over a 130 mile stretch of the Sacramento River, exposing embryonic and larval stages of several anadromous fishes (Cornacchia et al., 1984). Moreover, thiobencarb residues in river water entering the City of Sacramento's municipal water treatment plant were reported to impart a bitter taste to the tap water (CDHS, 1984).

As a result of these water quality problems, the State Water Resources Control Board (SWRCB) recommended "best management practices" for irrigation aimed at increasing the residence time of rice field tail-water within farm or district drainage systems (Cornacchia et al., 1984). Previous laboratory and field studies by Soderquist et al., (1977), Crosby (1983), and Ross et al., (1984) had shown that the half-life of molinate in water was usually less than a week indicating that substantial reductions in residue levels could be gained through longer field water holding periods, or from farm and district drain water recycling. A study by Ross et al., (1984) concluded, however, that thiobencarb dissipation from a rice field was much slower, suggesting that thiobencarb residues would be better controlled in a recirculation system. The Department of Food and Agriculture (CDFA) took a key step in implementing these practices during 1984 by increasing the manadatory field water holding period after an application from four to eight days for Ordram 10G (10 percent molinate granular formulation), and limiting the sales of Bolero 10G to 90 percent of the total pounds sold during 1983. In addition, farm tail-water recycling was promoted by CDFA by exempting those rice growers who recirculated rice field tail-water within their farms from the holding periods.

The following study examines the effectiveness of a farm and reclamation district recirculation system to reduce the levels of thiobencarb and molinate entering the Sacramento River and Sacramento-San Joaquin Delta-Estuary. Pesticide applications and discharges from Heidrick Farms Inc. and Reclamation District 108 were examined over the 1984 growing season. Mass emission of molinate and thiobencarb from Reclamation District 108 to the Sacramento River was compared to that estimated for 1982, i.e., prior to extending the field holding period or intensive drain water recirculation. In addition, selected areas were sampled within the Sacramento Valley to investigate suspected sources of rice herbicide discharges to the lower Feather River and to characterize the spatial distribution of herbicide residues within the Sacramento-San Joaquin Delta-Estuary. Herbicide concentrations in the Sacramento River (above Sacramento), the Colusa Basin Drain, Sacramento Slough, and other Sacramento Valley drainages during 1984 have been reported elsewhere (Finlayson and Lew, 1984).

METHODS

Pesticide Use Reporting System (PURS)

A record of Ordram and Bolero use within Reclamation Disticts 108 (RD108) and 2035 (Heidrick Farms Inc.) was obtained from the Environmental Hazards Assessment Program (EHAP) of CDFA for 1984. Herbicide usage within RD108 during 1982 was retrieved from the PURS archives located at the University of California (Davis), Department of Environmental Toxicology. Reclamation district boundaries were converted into township range-section survey coordinates to compute the total pounds of molinate and thiobencarb (active ingredients) applied daily within each district drainage system. It should be pointed out that the 1982 data set lacked any potential information concerning the application of Ordram formulations by non-licensed pesticide applicators (e.g. a grower) since Ordram was not classified as a "restricted material" until 1984. A ful description of the CDFA Pesticide Use Reporting System can be found elsewhere (CDFA, 1978).

Monitoring Schedule

Water and fish were sampled from selected rice drainages within the Sacramento Valley beginning May 2 and ending June 29, and analyzed for molinate and thiobencarb. Three general regions were monitored: (I) drainages west of the Sacramento River (Reclamation Districts 108 and 2035); (II) drainages east of the Sacramento River (Butte Slough and Natomas Drain RD 1000) and east of the Feather River (Honcut Cr., Bear Cr., and Jack Sl.); and (III) the lower Sacramento River and the Sacramento-San Joaquin Delta-Estuary. Sampling locations are shown in Figures 1 and 2, while expanded station descriptions are provided in Table 1.

Ia. Reclamation District 2035 (Heidrick Farms Inc.):

Heidrick Farms Inc. (HFI), located within the Yolo Bypass flood plain between Highways I-80 and I-5, operated a closed farm irrigation, recirculation system (Figure 1; Figure A-1). In return for completely recirculating tailwater, HFI was granted an exemption to the field water holding periods required by the Ordram and Bolero product labels (eight and six days, respectively). Field return flows were recycled within the farm until June 6 when drain water was discharged to the Toe Drain and northern Delta. During the recycling period, replicate pairs of surface

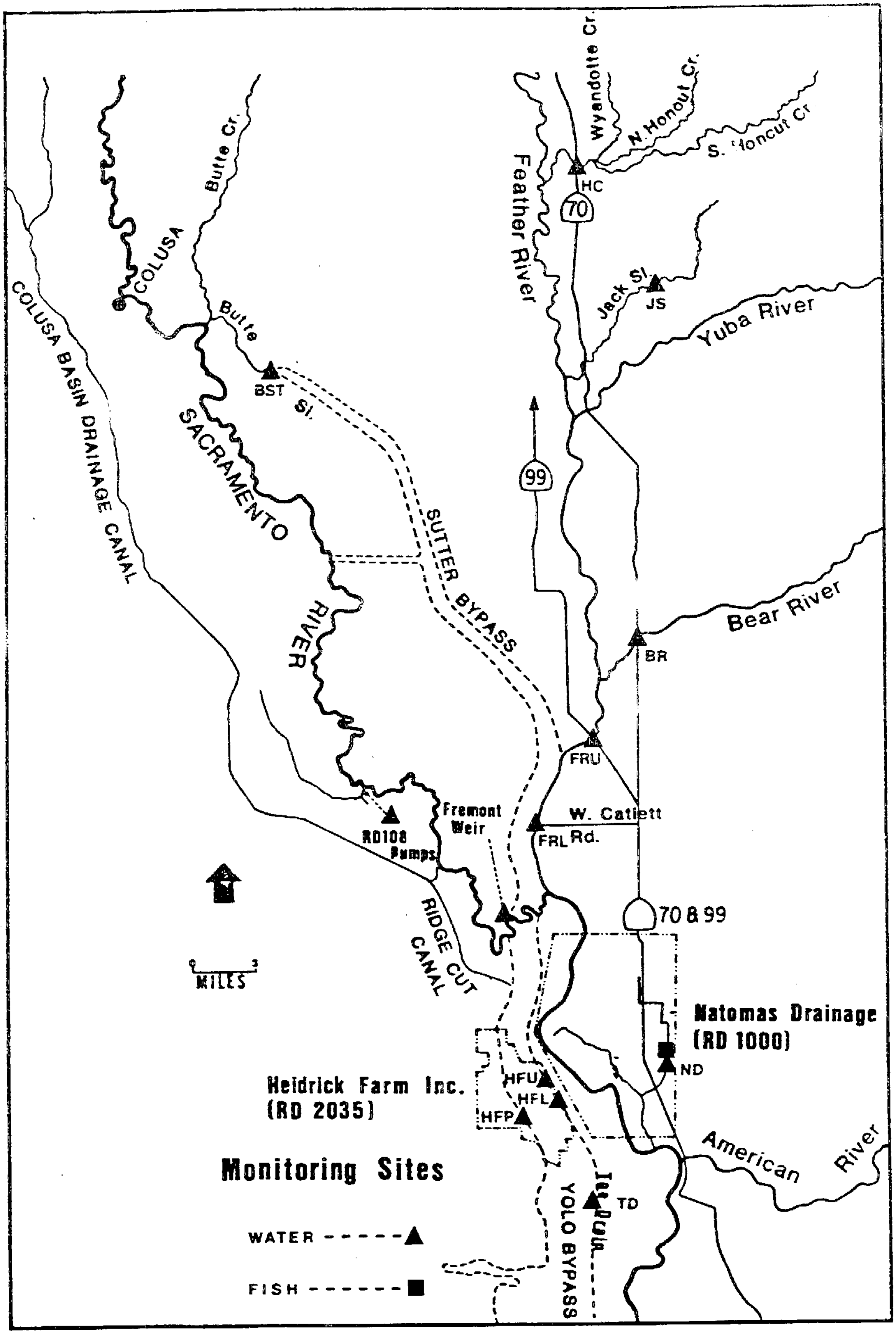


Figure 1. SACRAMENTO VALLEY SAMPLING STATIONS. REFER TO TABLE 1 FOR EXPANDED STATION DESCRIPTIONS. A MAP OF THE HEIDRICK FARMS INC. RECIRCULATION AREA IS SHOWN IN FIGURE A-1.

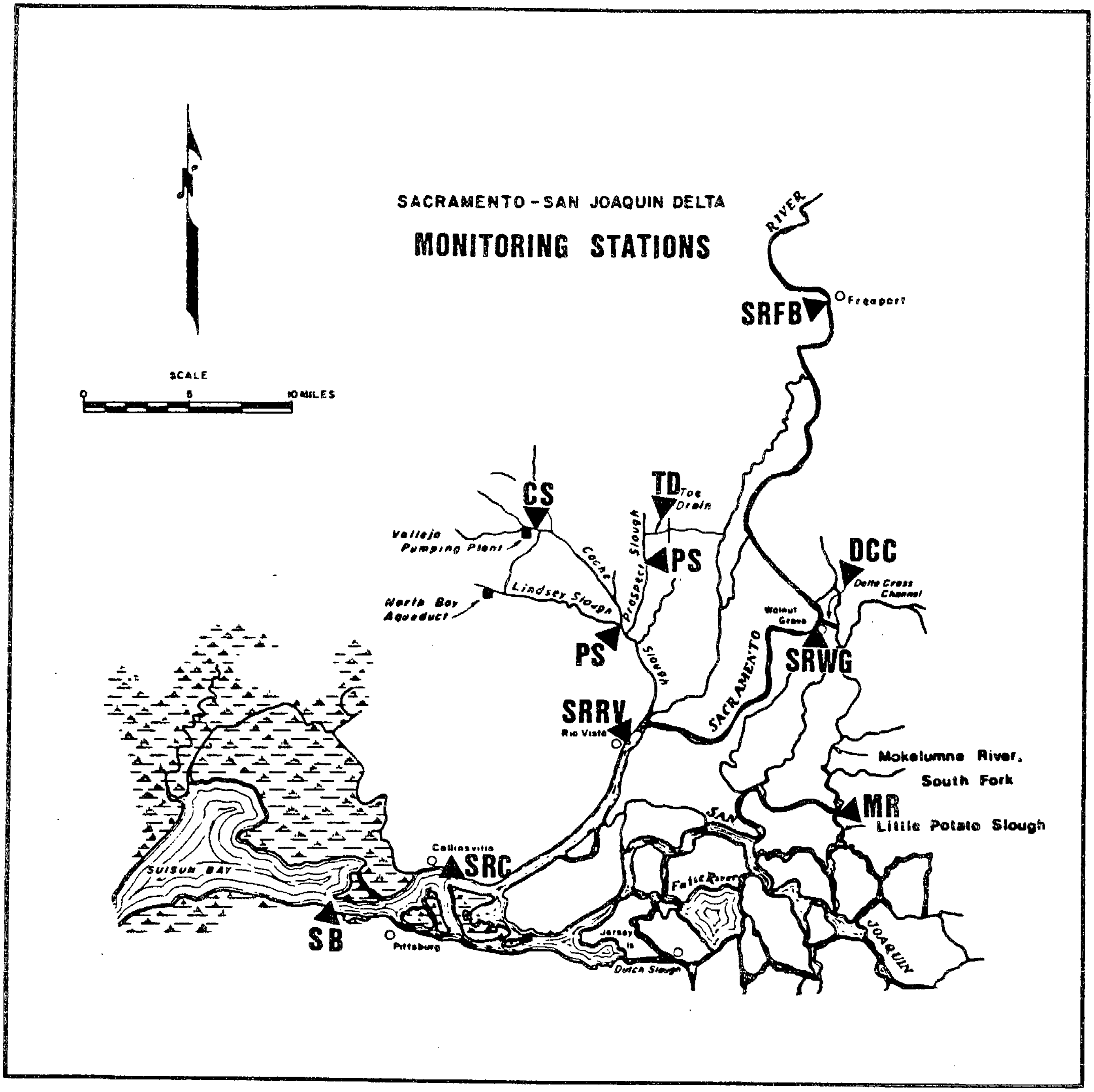


Figure 2. SACRAMENTO-SAN JOAQUIN DELTA-ESTUARY SAMPLING STATIONS. REFER TO TABLE 1 FOR EXPANDED STATION DESCRIPTIONS.

Table 1. STATION DESCRIPTIONS AND SAMPLING PERIODS FOR THE LOWER SACRAMENTO RIVER AND THE SACRAMENTO-SAN JOAQUIN DELTA-ESTUARY.

STATION DESCRIPTION	CODE	SAMPLING PERIOD
Stations East of Sacramento River		
Bear River, Highway 70 Bridge	BR	5/25
Butte Slough, Wooden Bridge near Tarke Road	BST	5/18-6/7
Feather River (Upper), West Cattlett Road	FRU	6/1
Feather River (Lower), Highway 99 Bridge	FRL	5/25
Honcut Creek, Highway 70 Bridge	HC	6/1
Jack Slough, Jack Slough Road Bridge	JS	5/25, 6/1
Natomas Drain (East), Del Paso Road Bridge	ND	5/24-6/29
Sacramento Slough, Lower Gaging Station	SS	6/19
tations West of Sacramento River		
Colusa Basin Drain, Road 99E	CBD	6/12-6/29
Heidrick Farms (Pump), ten yards downstream of pump	HFP	5/2-6/29
Heidrick Farms, Upper Discharge to Tule Canal	HFU	6/6-6/29
Heidrick Farms, Lower Discharge to Tule Canal	HFL	6/6-6/29
RD108, West of Rough and Ready Pump Station	RD108	5/2-6/29
Toe Drain, Highway 80 Bridge	TD	6/7-6/29
acramento River Stations		
Collinsville	SRC	5/26, 5/30
Freeport Bridge	SRFB	5/21, 5/29
Fremont Weir	SRFW	6/6-6/8
Rio Vista Bridge	SRRV	5/21, 5/29
Walnut Grove Bridge	SRWG	5/21, 5/29
acramento-San Joaquin Delta-Estuary Stations		
Northern Delta		
Cache Slough, Vallejo Pumping Plant	CS	5/21, 5/29
Toe Drain	TD	5/21, 5/29
Lindsey Slough, Cache Slough Confluence	LS	5/21, 5/29
Prospect Slough, Steel Towers	PS	5/21, 5/29
Central Delta		
Delta Cross Channel, Channel Gates	DCC	5/21, 5/29
Mokelumne River, Little Potatoe Slough Confluence	MR	5/21, 5/29
Western Delta		
Suisun Bay, Chipps Island	SB	5/26, 5/30

water samples were collected near the intake canal of the main recirculation pump. Samples were taken from drain water discharging to the Toe Drain and downstream of the discharge after June 6. Drain water was also sampled from the recirculation pump by the University of California Agricultural Extension (Davis) from May 16 to June 21 and sent to Stauffer Chemical Company and Chevron Chemical Company for analysis. Sample handling and the analytical procedures used by both companies has been described elswhere (Cornacchia et al., 1984).

Ib. Reclamation District 108:

Drain water was sampled from the forebay of the district's "Rough and Ready" Pumping Plant located on the Sacramento River 9.5 miles above Knights Landing (Figure 1). Daily composite samples were prepared by RD108 personnel by combining three equal volume surface grab samples drawn at approximately 2400, 0600, and 1200 (MST). Replicate pairs of grab samples were also collected bi-weekly during the peak discharge and less frequently during the early and late part of the discharge period (Table A-7).

Sampling was performed over a twenty-five hour period on May 16 and again on May 24 to estimate the daily variability in herbicide concentrations. Five replicate grab samples were collected every six hours from the catwalk above the forebay. Differences in concentrations due to the time of collection were tested using the Kruskal-Wallis procedure and the Dunn's multiple comparision test (Daniel 1978).

II. Drainages East of the Sacramento and Feather Rivers:

Butte Slough, which drains the Butte Basin, was sampled at its junction with the Sutter Bypass during the peak herbicide discharge period (Figure 1). Receiving waters from rice growing districts east of the Feather River, including Honcut Cr., Jack Sl., and Bear Cr., were sampled during the same period to examine their relative discharge to the lower Feather River below the Honcut Creek confluence. Water and fish samples were also collected near the recirculation pump of the Natomas east main drain (RD1000) (Figure1). Although RD1000 did recycle some rice field water, a total of 1664 acre-ft was discharged to the Sacramento River just above the American River during May and June.

III. Lower Sacramento River and Sacramento-San Joaquin Delta-Estuary:

An areal survey of molinate and thiobencarb concentrations in delta waters was conducted in late May and early June. Water samples were collected in the lower Sacramento River between Freeport and Suisun Bay (Figure 2) to examine the distribution of rice herbicide residues within the

Sacramento-San Joaquin Delta-Estuary. Sampling was also performed in the central Delta between the Delta Cross Channel and the San Joaquin River, the major SWP and CVWP diversion route from the Sacramento River. As in 1983 (Cornacchia et al., 1984), the Cache Slough drainage was monitored for the presence of molinate and thiobencarb near the City of Vallejo Municipal Water Intake.

Sample Collection

Grab samples were collected ($<$1.0 meter from the surface) in one quart, amber bottles pre-rinsed with methylene chloride and sealed with teflon-lined caps. Samples were taken by boat from the main channel of the Sacramento River and sloughs of the Sacramento-San Joaquin Delta, and from the shore of smaller waterways. Water samples were transported on ice and in the dark to California Analytical Laboratories (CAL) within 24 hours of collection. Chain of custody records are on file at CAL and SWRCB.

Brown bullhead (*Ictalurus nebulosus*) and common carp (*Cyprinus carpio*) were collected from the East Natomas drainage canal (RD1000) (Figure 1) on May 24 using a baited hoop net. Fish were double wrapped with aluminum foil, packed in dry ice, and transported to the CDFG, Fish and Wildlife Water Pollution Control Laboratory for analysis. Fish skeletal muscle (fillets) were composited by species and analyzed for molinate and thiobencarb following the procedure described in Finlayson et al. (1982).

Thiocarbamate Analysis

Water samples were shaken prior to extraction to determine total molinate and thiobencarb residue concentrations. A 400 ml aliquot was transferred into a 500 ml separatory funnel and extracted with two 50 ml portions of dichloromethane. The pooled extracts were concentrated with 1 ml of isooctane using a rotary evaporator (bath temperature <35 C). The concentrated extract was combined with 8 ml of hexane and further concentrated under nitrogen to a final volume of 1 ml. Extracts were analyzed for thiobencarb and molinate by nitrogen-phosphorus gas chromatography (NP-GC) using a 10 percent SP2250 column on a Finnigan gas chromatograph and selected samples were confirmed using a Finnigan mass spectrometer. The NP-GC detection limit for both thiocarbamates was 1.0 ug/l. Recovery rates for method spikes in distilled water ranged from 71 to 120 percent ($\bar{X}$ = 92 percent, SEM = 3.0 percent) for molinate and 80-130 percent ($\bar{X}$ = 102 percent, SEM = 3.4 percent) for thiobencarb (n = 17).

Reclamation District 108 Mass Emission Calculations

The mass discharge of molinate and thiobencarb from the RD108 pumping plant into the Sacramento River was estimated from daily release values compiled by the district manager (Granicher, 1984). Herbicide emission curves were constructed by three methods. Daily discharge rates were obtained from the product of the drain water volume pumped each day and: (1) the mean concentration of replicate grab samples, (2) the expected concentration predicted by best-fit polynomial regression equations using data from (1), and (3) herbicide concentrations from daily composite samples collected by RD108 personnel (SVWQC, 1984). A mass emission curve was plotted for the first method using a NEC Model APC microcomputer and a Houston Instruments Model DMP-29 plotter. The area under the plotted curve (i.e., the total mass discharged) was measured using a Carl Zeiss Videoplan planimeter. Total mass discharged was estimated from the the latter two methods as the sum of daily discharges. For comparative purposes, a mass emission curve was also constructed for 1982 by the first method using the herbicide monitoring data presented in Finlayson et al. (1983a), and daily RD108 pumping rates provided by Granicher (1984). The fraction of herbicide applied within RD108 that was discharged to the Sacramento River was estimated for 1982 and compared to 1984. In addition, the lag period between application and discharge was estimated as the number of days between 50 percent of cumulative totals (Cornacchia et al., 1984).

Physicochemical Monitoring

Water temperatures were recorded at each station during sampling. Electrical conductivity (EC) was measured in the field at some stations using a Myron Deluxe DS Meter (Model 532 [illegible]) according to APHA et al. (1975). Field samples were collected from the shore in a one pint plastic container. Meter calibration was checked at each site and the cell cup rinsed with sample water prior to analysis. Replicate samples were collected and transported on ice to Radian Corporation Laboratories (RCL) for EC analysis within 24-hours of collection. No significant difference (alpha .01) could be detected between laboratory or field analyzed replicate samples (student t-test, n = 8).

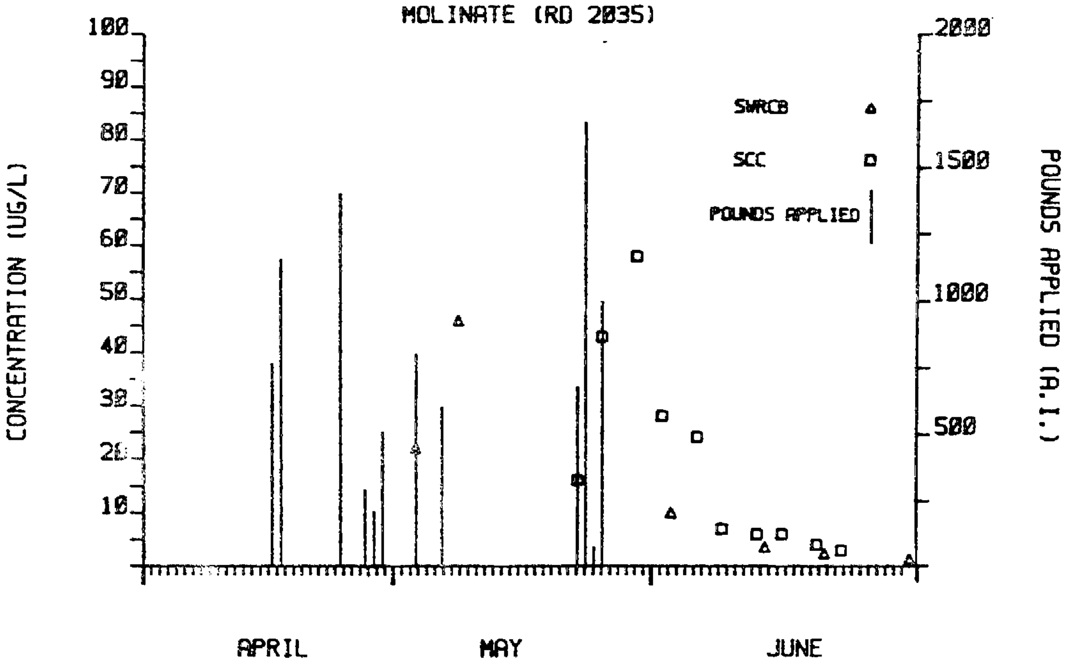
RESULTS

I. Drainages West of the Sacramento River

A. RD2035 (Heidrick Farms Inc.):

A total of 13,545 pounds of molinate active ingredient (a.i.) and 21,608 lbs a.i. of thiobencarb were applied to Heidrick Farms Inc. (HFI) during the 1984 rice-growing season (Table A-2; Table A-3). Ordram (molinate) applications began April 19 and were completed by May 23. Ordram 8E (emulsifiable concentrate) was the predominant formulation used; 8E treatments ended May 18 coinciding with the initiation of 10G treatments. Bolero (thiobencarb) applications (10G), commenced on May 7 and continued until May 29. Field return flows were recycled within the HFI drainage system until June 6 when they were discharged into the Toe Drain.

The level of molinate measured at the farm recirculation pump appeared to rise after each series of applications (Figure 3). The peak concentration detected (58 ug/l) was measured on May 28, five days after the last treatment with Ordram 10G. Molinate residues from inital release water at the upper



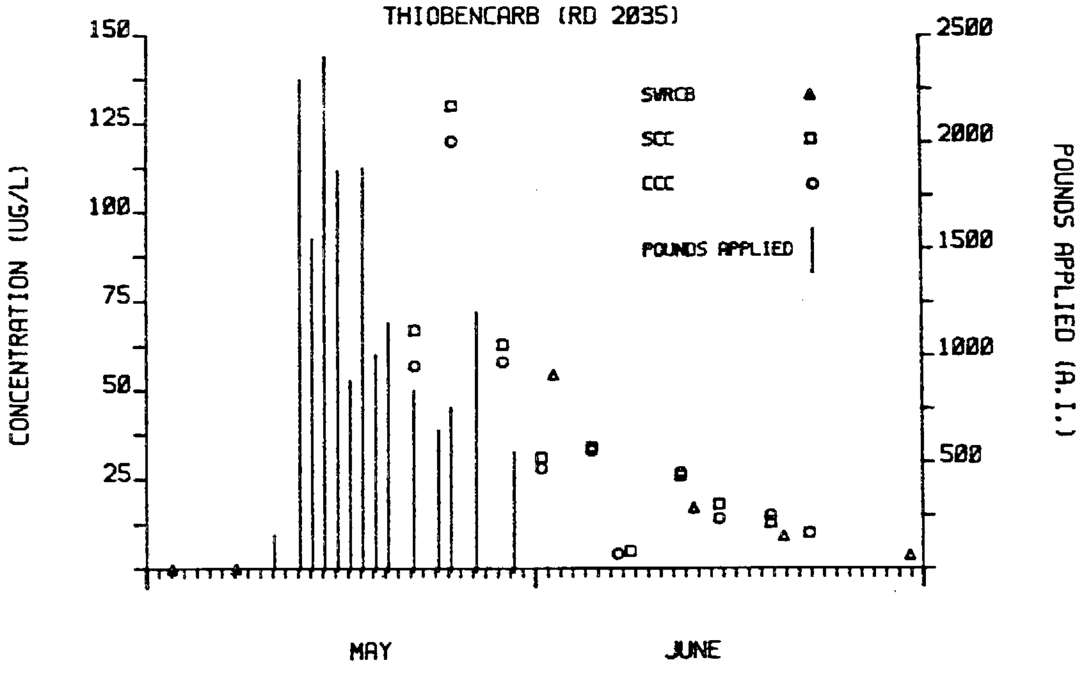


Figure 3. MOLINATE AND THIOBENCARB CONCENTRATIONS MEASURED IN THE HEIDRICK FARMS RECIRCULATION SYSTEM. VERTICAL BARS DENOTE THE POUNDS OF HERBICIDE (A.I.) APPLIED WHILE THE SYMBOLS REPRESENT CONCENTRATIONS MEASURED BY THE STATE WATER RESOURCES CONTROL BOARD (SWRCB), STAUFFER CHEMICAL COMPANY (SCC) AND CHEVRON CHEMICAL COMPANY (CCC).

(1.3 ug/l) and lower (8.9 ug/l) discharge sites had decreased, 98 percent and 85 percent, respectively, from peak in-farm concentrations (Table A-4).

The peak in-farm concentration of thiobencarb was 130 ug/l (May 24), measured after 90 percent of the total pounds of thiobencarb had been applied (Figure 3; Table A-3). Drain water discharged from HFI to the Toe Drain initially contained levels of thiobencarb ranging from 24 to as high as 69 ug/l which corresponds to 18 and 53 percent of the peak level measured. Over the subsequent three weeks, thiobencarb concentrations decreased to 3.8 ug/l (HFL) and 5.8 ug/l (HFU) measured on the last day of sampling (June 29).

Monitoring conducted in the Toe Drain (receiving waters for HFI) on the second day of farm discharge (June 7), detected a mean of 12 ug/l of molinate and 11 ug/l thiobencarb (Table 2). Background levels measured at the mouth of Prospect Slough on May 21 and 29 prior to any farm releases were 2.0 ug/l molinate and less than 1.0 ug/l, respectively. Following June 6, residue levels of both herbicides within the Toe Drain decreased over a three week period to near the reported detection limit.

Table 2. MOLINATE AND THIOBENCARB CONCENTRATIONS IN THE TOE DRAIN (TD).

DATE 1/	TEMPERATURE (°C)	EC 2/	UG/1 MOLINATE	UG/1 THIOBENCARB
6-7	21.1	700	13	12
7r			10	10
12	23.3	850	9.5	7.5
12r			11	9.5
19	24.9	650	3.7	2.6
19r			5.3	3.2
29	25.5	600	2.5	1.7
29r			2.0	1.2

1/ r = replicate
2/ Electrical conductivity, dS/m.

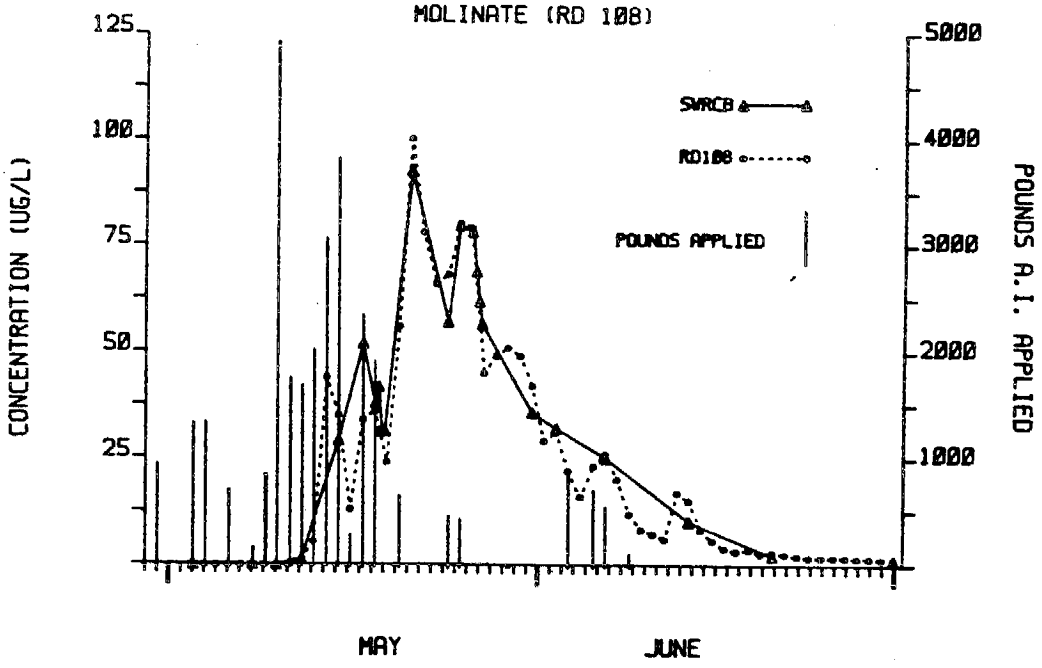
Electrical conductivity (EC) of recirculated farm irrigation water was 760 and 800 dS/m on the first day of farm releases to the Toe Drain (Table A-4). The peak EC value was 1000 dS/m measured on June 8 at the "lower" discharge (Figure A-1). Toe Drain EC values ranged from 600 to 850 dS/m between June 7 and June 29. Water temperatures measured in the Toe Drain were slightly warmer than those measured in HFI and ranged from 21.1 to 25.5 C between June 6 and 29.

B. Reclamation District 108:

A total of 31,343 pounds of molinate and 19,004 pounds of thiobencarb were applied within RD108 during 1984 (Table A-5; Table A-6). Ordram 10G treatments occurred between April 20 and June 7 at an application of 3 to 5 lbs per acre. Bolero 10G was applied (4 lbs/acre) over a narrower time period starting May 7 and ending June 3. The district pump discharged to the Sacramento River usually during non-peak, electrical use hours (i.e., other than 1200-1800 MST), pumping a total of 13,987 acre-feet during the months of May and June.

Peak molinate and thiobencarb concentrations were detected in the forebay of the pump station during the last two weeks of May (Table A-7; Figure 4). Molinate levels increased to 90 and 95 ug/l on May 20 while thiobencarb concentrations peaked at 17 and 18 ug/l on May 23. Concentration curves plotted with residue values from composite samples were nearly identical to those plotted using the means of replicate grab samples (Figure 4).

Sampling of the RD108 forebay over a 24-hour period indicated that the mean levels of molinate decreased (Figure 5; Table 3). Timing of sample collection significantly affected mean concentrations according to the Kruskal-Wallis procedure ($P < .01$). Comparisons between 6 hour collections (treatment groups) using Dunn's multiple comparison test detected significant differences (i.e., decreases) between the first and final two replicate sample sets. A similiar trend was found for thiobencarb during the 24-hour sampling period initiated May 24 but was not detected during May 16-17. Replicate means from May 16 and 17 thiobencarb analyses were nearer to the detection limit and had relatively high coefficients of variation (7.8 - 38.1 percent). In general, the relative precision of molinate replicate field values were consistently



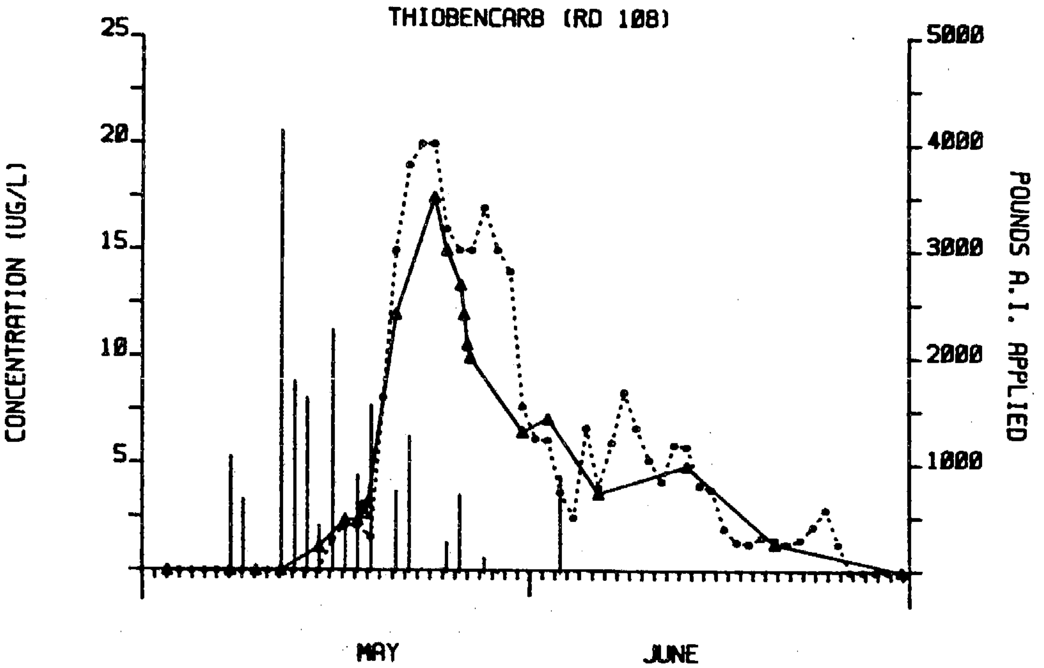
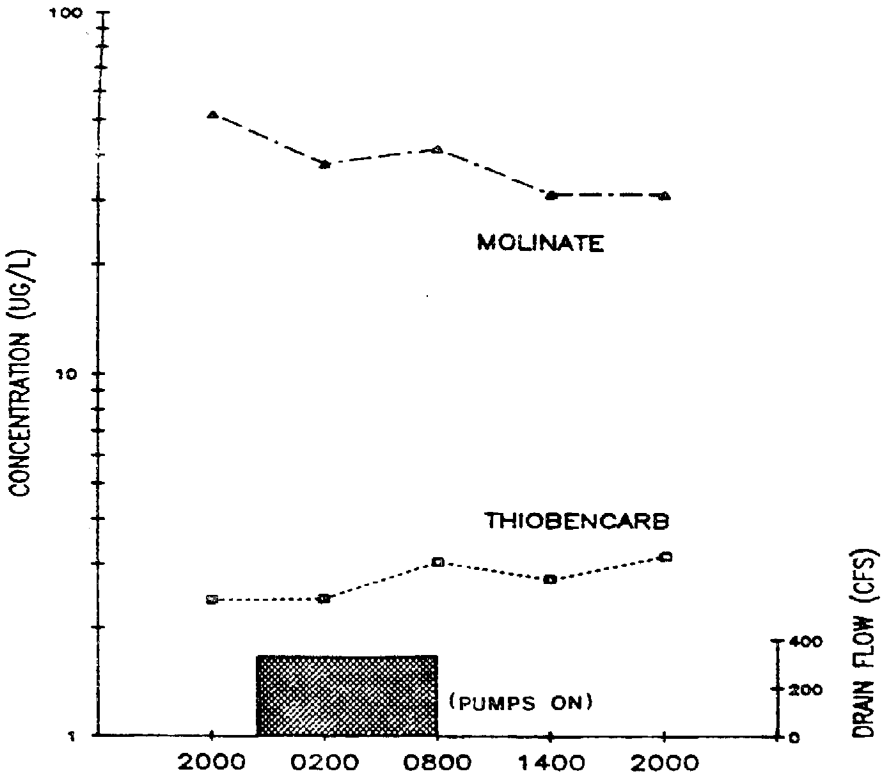


Figure 4. MOLINATE AND THIOBENCARB CONCENTRATIONS DETECTED IN THE ROUGH AND READY PUMPING PLANT FOREBAY OF RECLAMATION DISTRICT 108. SAMPLES COLLECTED BY RECLAMATION DISTRICT 108 WERE COMPOSITES WHILE SWRCB VALUES REPRESENT THE MEAN OF REPLICATE GRAB SAMPLES. VERTICAL BARS DENOTE THE TOTAL POUNDS OF HERBICIDES APPLIED WITHIN RD108.

May 16—17



May 24—25

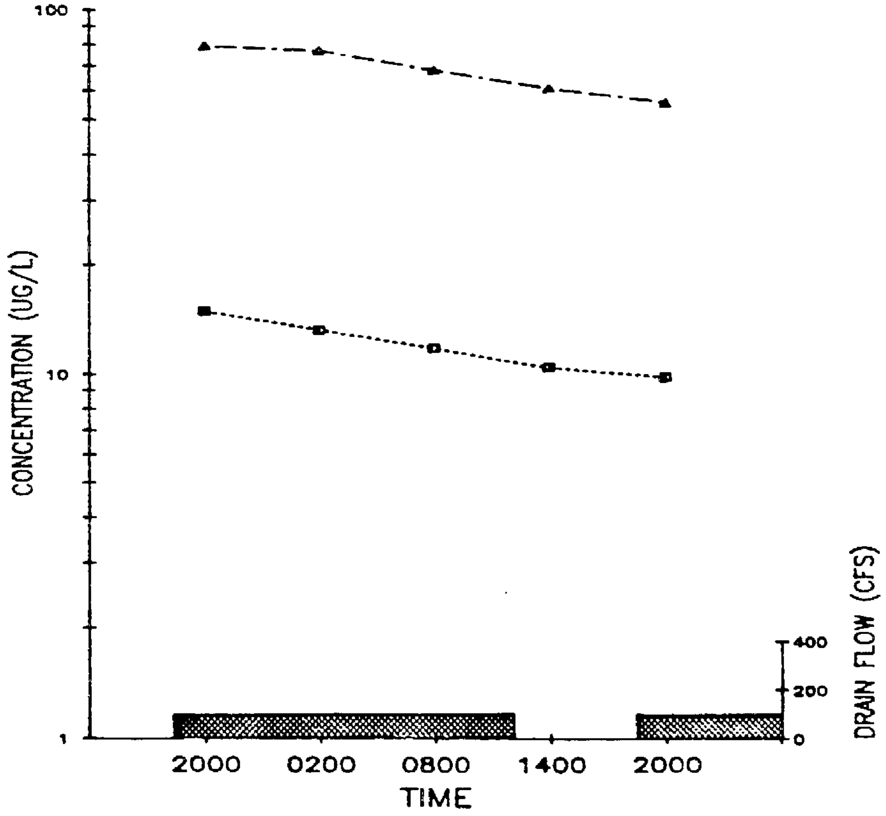


Figure 5. DIEL CHANGES IN MOLINATE AND THIOBENCARB CONCENTRATIONS BETWEEN MAY 16 AND 17, AND MAY 24 AND 25 (SEE ALSO TABLE 3; TABLE A-8).

Table 3. DIURNAL VARIABILITY IN MOLINATE AND THIOBENCARB CONCENTRATIONS DETECTED IN RECLAMATION DISTRICT 108 DRAIN WATER.[1]

a. May 16

HERBICIDE	RUN	$\bar{X}$ (UG/L)[2]	SEM[3]	N[4]	RANGE	CV (%)[5]
Molinate						
	I.	52.0 a	1.22	5	49 - 56	5.27
	II.	37.8 a,b	0.970	5	36 - 41	5.74
	III.	41.6 a	0.927	5	39 - 44	4.98
	IV.	31.3 b,c	0.946	4	30 - 34	6.06
	V.	31.2 b,c	0.970	5	28 - 34	6.95
Thiobencarb						
	I.	2.40 a	0.0837	5	2.1-2.6	7.80
	II.	2.42 a	0.307	5	1.9-3.6	28.4
	III.	3.04 a	0.172	5	2.7-3.7	12.7
	IV.	2.73 a	0.347	4	1.9-3.6	25.5
	V.	3.16 a	0.539	5	2.1-4.7	38.1

b. May 24

HERBICIDE	RUN	$\bar{X}$ (UG/L)[2]	SEM[3]	N[4]	RANGE	CV (%)[5]
Molinate						
	I.	79.6 a	1.72	5	76 - 86	4.83
	II.	77.6 a,b	1.25	5	75 - 81	3.60
	III.	68.8 a,b,c	2.01	5	63 - 75	6.53
	IV.	61.6 b,d	0.927	5	60 - 65	3.37
	V.	56.4 c,d	1.08	5	53 - 59	4.27
Thiobencarb						
	I.	15.0 a,b	0.837	5	13 - 18	12.5
	II.	13.4 a	0.600	5	12 - 15	10.0
	III.	12.0 a,b	0.316	5	11 - 13	5.89
	IV.	10.6 a,b	0.258	5	9.9- 11	5.45
	V.	10.0 b,c	0.898	5	9.8- 10	0.90

[1] See Table A8 for individual sample concentrations and times.

[2] Treatments with any letter in common did not significantly differ according to Dunns Multiple Comparison Test.

[3] Standard Error of the Means.

[4] Number of replicates.

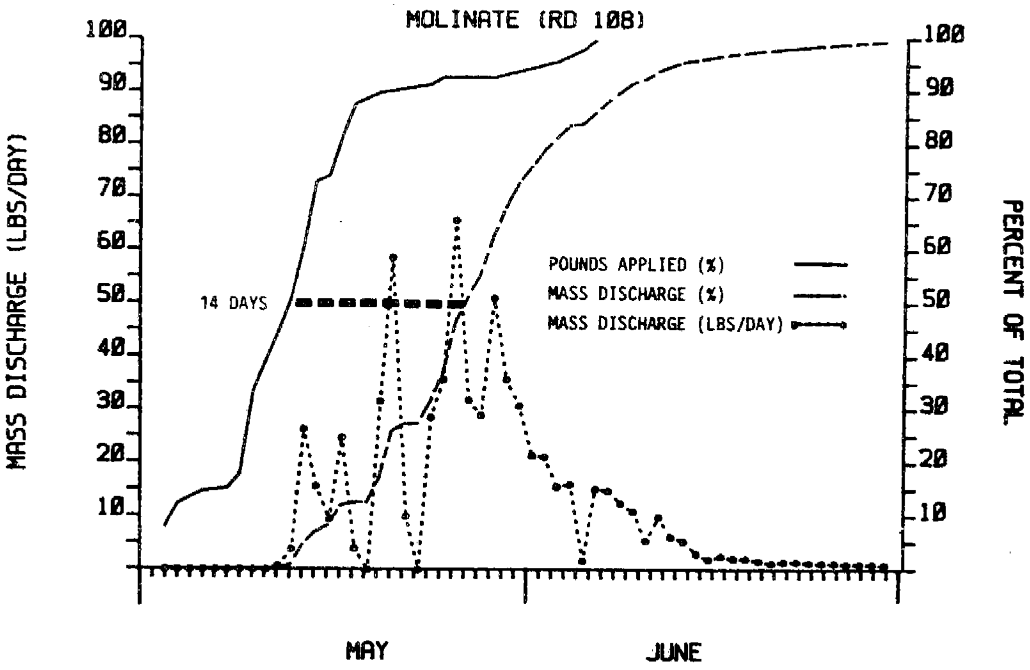
[5] Coefficient of Variation.

better than that observed for thiobencarb.

The estimated amount of thiocarbamate residue discharged by RD108 to the Sacramento River during 1984 totalled between 678 to 721 lbs. of molinate and 114 to 152 lbs. of thiobencarb (Table A-9; Figure 6). The mass discharged as well as the peak concentration of both herbicides declined from levels measured in 1982 (Table 4). The fraction of total pounds applied that was released to the river was reduced indicating that less herbicide per acre was being discharged. A comparison of 1982 and 1984 pumping records showed that the district recirculation reduced return flows per rice acre flooded by 52 percent and, combined with the eight day holding period, increased the retention (i.e., the lag period) of herbicide residues within the district by approximately 11 days for molinate and 9 days for thiobencarb (Table 5; Figure 6). Recirculation practices did not significantly elevate electrical conductivity: EC measured between May 14 to June 29 ranged between 380 to 550 dS/m.

II. Drainages East of the Sacramento River

A maximum concentration of 55 ug/l molinate and 1.9 ug/l thiobencarb was measured in samples collected from Butte



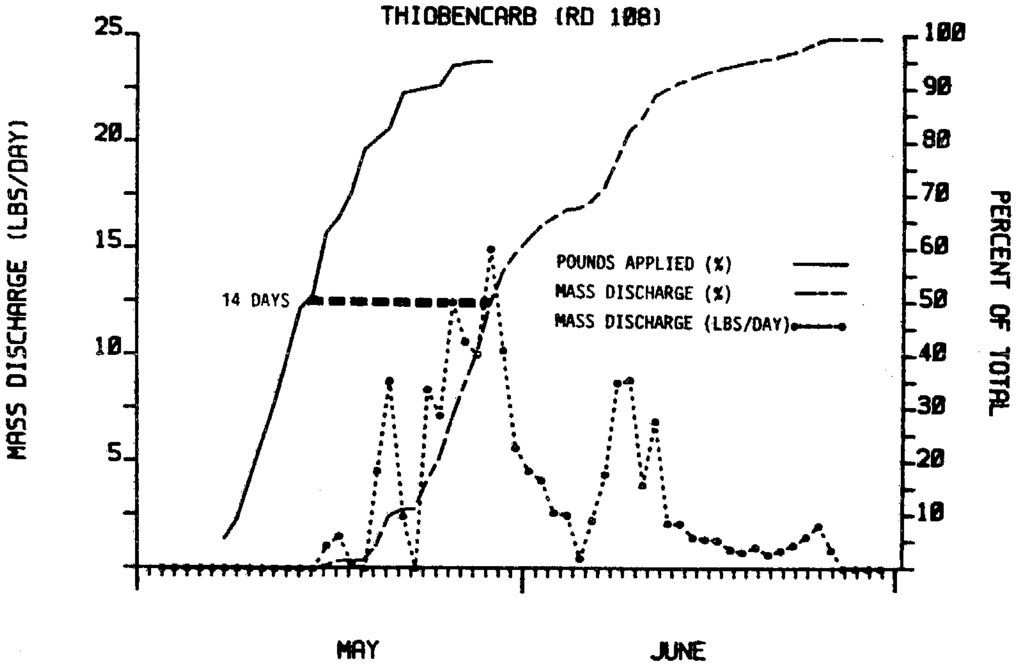


Figure 6. MASS EMISSION OF MOLINATE AND THIOBENCARB FROM RD108 TO THE SACRAMENTO RIVER (9.5 MILES ABOVE KNIGHTS LANDING). LAG TIMES REPORTED IN TABLE 5 ARE CALCULATED AS THE NUMBER OF DAYS BETWEEN 50 PERCENT OF TOTAL APPLICATIONS AND MASS DISCHARGED.

Table 4. MASS EMISSIONS OF MOLINATE AND THIOBENCARB FROM RECLAMATION DISTRICT 108 DURING 1982 AND 1984.

HERBICIDE (A.I.)	YEAR	APPLIED (LBS)	DISCHARGED (LBS)	D:A[1] (%)	PEAK CONCENTRATION (UG/L)
Molinate	1982	15,138	3,768	25	187 [2]
	1984	31,343	721	2.3	95
Thiobencarb	1982	63,038	3,006	4.8	110 [2]
	1984	19,005	125	0.7	18

[1] Discharged (lbs.)/Applied (lbs.)

[2] Source: Finlayson and Lew, 1983a.

Table 5. WATER VOLUME UTILIZATION AND MOLINATE AND THIOBENCARB LAG PERIODS BETWEEN POUNDS APPLIED AND RESIDUES DISCHARGED WITHIN RD 108.

YEAR	FLOODED[1] ACRES	ACRE FT.[1] DISCHARGE	ACRE FT./ACRE	LAG PERIOD[2] (DAYS) MOLINATE	LAG PERIOD[2] (DAYS) THIOBENCARB
1982	25,584	37,970	1.484	3	5
1984	19,552	13,987	0.715	14	14

[1] May and June total.

[2] Days between 50% of the cumulative 1.) pounds applied and 2.) pounds discharged.

Slough during the peak Sacramento Valley thiocarbamate discharge period (May 18 to June 6). The rice growing districts located along the eastern border of the Feather River discharged to the river at Honcut Creek and Jack Slough (Figure 1; Table 6). Peak molinate concentrations measured the same day at Honcut Cr. and Jack Sl. were 32 and 28 ug/l, respectively. Neither herbicide was detected in the one sample collected from the Bear River, a major tributary of the lower Feather River. The single water sample collected on May 25 from the Feather River was positive for molinate (2.6 ug/l) and less than 1.0 ug/l for thiobencarb.

Peak molinate concentrations measured below the main recirculation pump of RD1000 were 74 and 77 ug/l on May 24, while the maximum thiobencarb level was 38 ug/l, detected on May 30 (Table A-10). Both molinate and thiobencarb residues were found in carp and brown bullhead collected on May 24 from the same area (Table 7). Maximum residue levels detected in skeletal muscle composites were 840 ng/g molinate and 2,000 ng/g thiobencarb.

Table 6. RICE HERBICIDE CONCENTRATIONS IN DRAINAGES EAST OF THE SACRAMENTO RIVER.

LOCATION	DATE 1/	TEMPERATURE (C)	UG/L	
			MOLINATE	THIOBENCARB
Bear River	5-25	23.3	<1	<1
Butte Slough	5-18	21.6	26	<1
	5-18r		24	<1
	5-24	23.8	54	<1
	5-30		55	<1
	6-07	19.9	27	<1.9
Feather River				
(W. Catlett Rd.)	6-01	19.9	<1	<1
	6-01r		<1	<1
(Hwy. 99)	5-25	20.5	2.6	<1
Honcut Creek	6-01	24.4	32	<1
Jack Slough	5-25	19.9	38	1.1
	6-01	21.1	28	1.2

1/ r = replicate

Table 7. THIOBENCARB AND MOLINATE RESIDUES DETECTED IN FISH COLLECTED FROM THE EAST NATOMAS DRAINAGE CANAL.1/

SPECIES	LENGTH (cm)	WEIGHT (g)	SKELETAL MUSCLE 1/ ng/g (BCF) MOLINATE	THIOBENCARB
Brown bullhead	26	256	420 (5.6)	1,200 (70)
(*Ictalurus nebulosus*)	23	165		
Common carp	28	374	840 (11)	2,000 (118)
(*Cyprinus carpio*)	42	1,161		

1/ CDFG Fish Pesticide Laboratory Report - Lab No. P-80dl (E.P. No. L-205-84). Skeletal muscle residues expressed in terms of wet weight.

2/ Bioconcentration Fact (BCF) estimated from the mean of replicate water sample collected 5-24-84 (Table A-10).

III. Lower Sacramento River and Sacramento-San Joaquin Delta-Estuary

The Cache Slough system was sampled on May 21 and May 29 which coincided with the period of peak molinate and thiobencarb discharge from the Colusa Basin Drain and Sacramento Slough (Figure 7; Figure 8). Concentrations of molinate measured in Cache and Prospect Sloughs did not exceed 7 ug/l and were less than the detection limit at the Upper Cache Slough station (Hastings Cut), near the domestic water intake for the City of Vallejo. Molinate levels in the Toe Drain (above Prospect Sough confluence), the major agricultural drain discharging to the Cache Slough system were lower than in Cache or Prospect Sloughs. Thiobencarb concentrations were less than detection in all samples collected from the northern Delta.

Water quality surveys conducted along the lower Sacramento River between May 21 to May 30 demonstrated that molinate discharged upstream into the Sacramento River above Verona is transported to the delta and estuary as far west as Chipps Island (Table A-11; Figure 7; Figure 8). Molinate concentrations measured on May 21 in the Sacramento River below Sacramento ranged between 14 ug/l at Freeport to 9.6 ug/l (9.9 and 9.2 ug/l averaged) at Rio Vista. Sacramento River water diverted through the Delta Cross

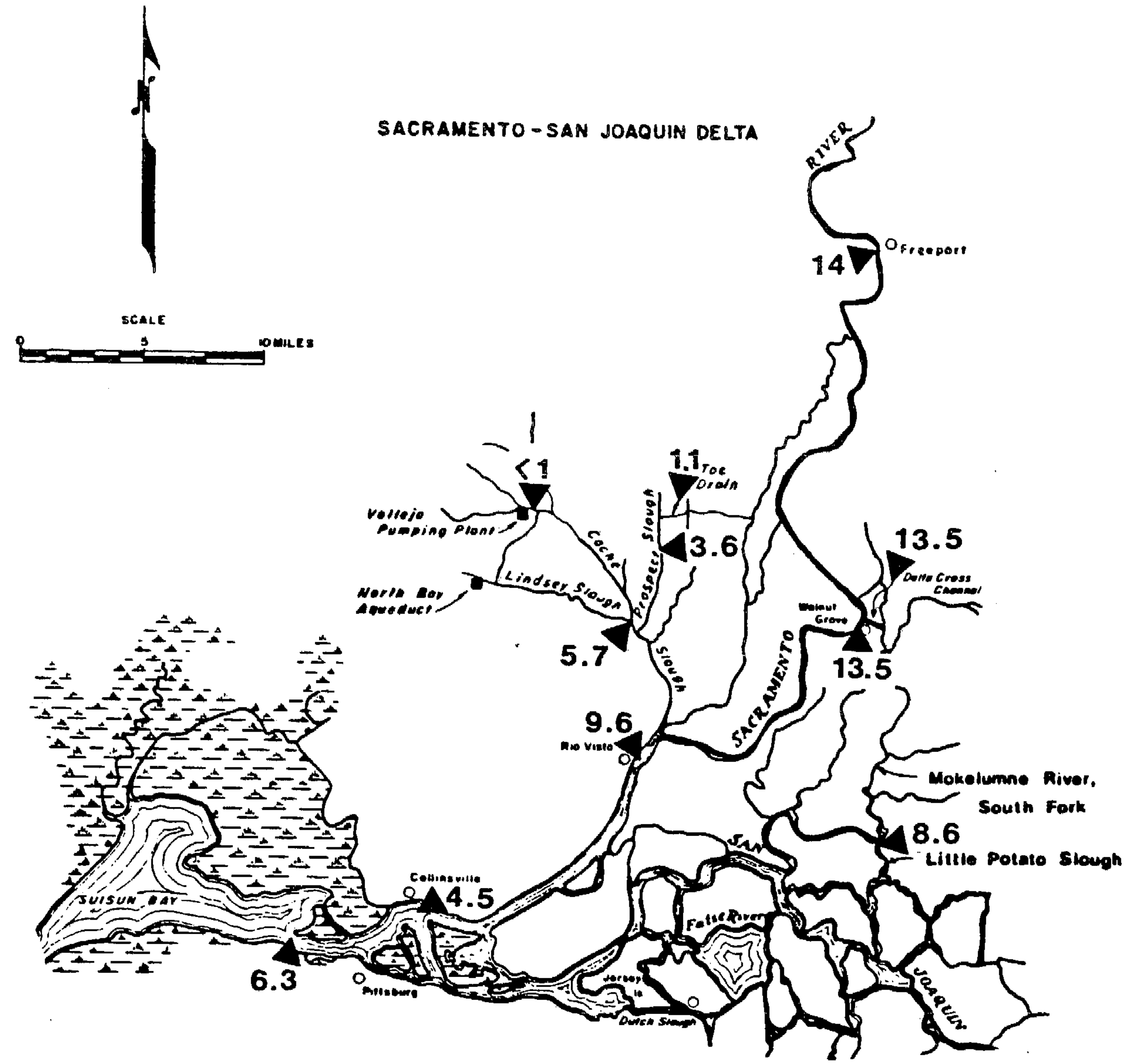


Figure 7. AREAL DISTRIBUTION OF MOLINATE RESIDUES (UG/L) IN THE SACRAMENTO-SAN JOAQUIN DELTA-ESTUARY ON MAY 21. STATIONS NEAR COLLINSVILLE AND WITHIN SUISUN BAY WERE SAMPLED ON MAY 26. RESIDUE VALUES ARE THE MEAN OF TWO REPLICATES.

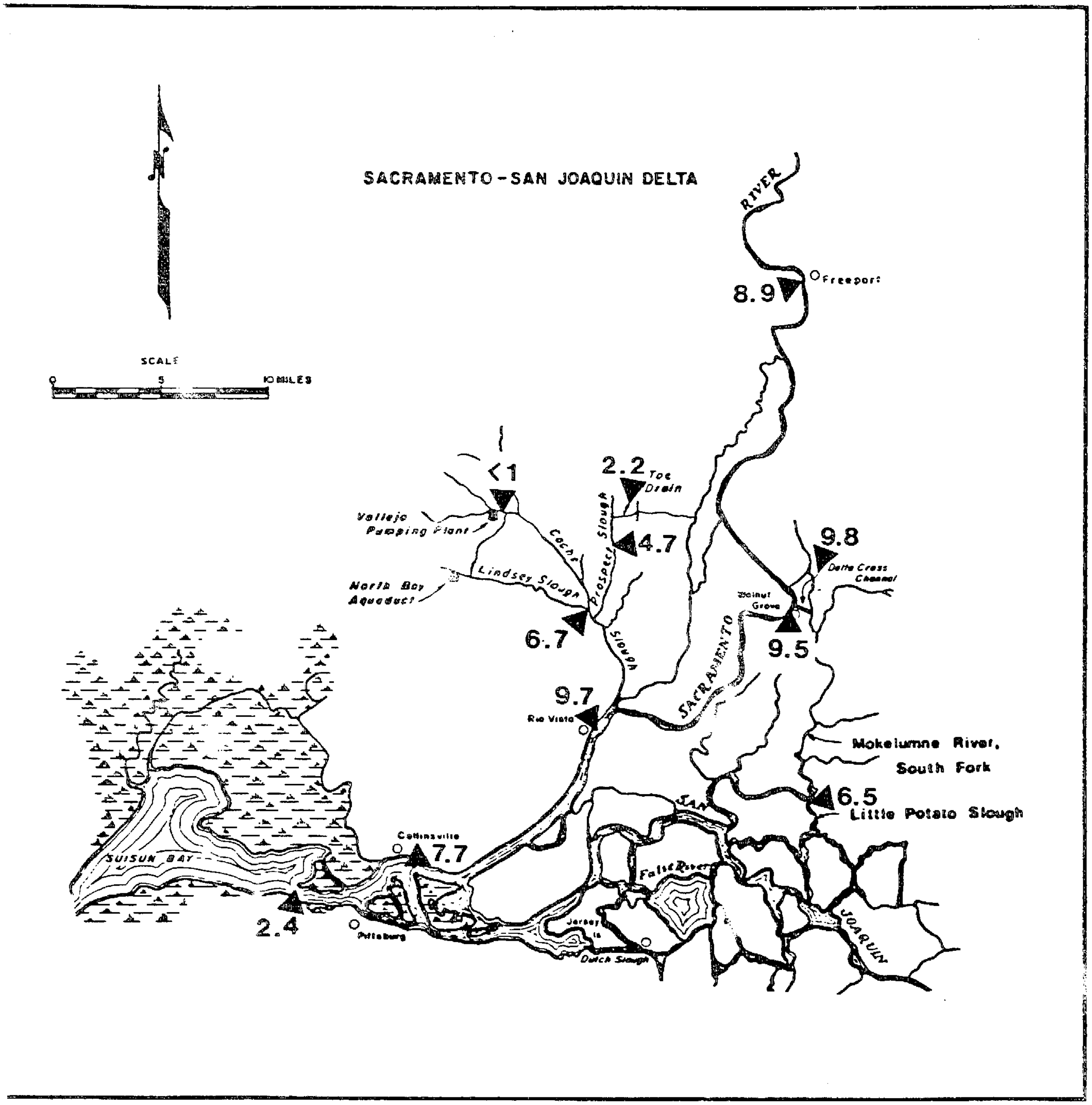


Figure 8. AREAL DISTRIBUTION OF MOLINATE RESIDUES (UG/L) IN THE SACRAMENTO-SAN JOAQUIN DELTA-ESTUARY ON MAY 29. STATIONS NEAR COLLINSVILLE AND WITHIN SUISUN BAY WERE SAMPLED ON MAY 30. RESIDUE VALUES ARE THE MEAN OF TWO REPLICATES.

Channel across the central Delta contained molinate concentrations slightly lower than that observed in the Sacramento River at Walnut Grove. Molinate levels detected five days later at Collinsville (2.2, 6.7 ug/l) and eastern Suisun Bay (4.3, 8.3 ug/l) were lower than those observed at Rio Vista. A similiar spatial pattern of molinate concentrations was observed during a water quality survey conducted on May 29 and 30. Thiobencarb concentrations measured in the lower Sacramento River during 1984 were usually less than or near the detection limit (1.6 ug/l).

DISCUSSION

The Heidrick Farms study clearly illustrates the effectiveness of a drain recirculation system to reduce the levels of molinate and thiobencarb in farm effluent. Several previous Sacramento Valley field studies have shown that molinate volatilizes relatively rapidly from a flooded rice field; half-lifes range from 3 to 10 days (see reviews by Crosby, 1983; Cornacchia et al., 1984). Thiobencarb dissipates more slowly from field water (t1/2 = >7 days), having a greater tendency to adsorb to sediment (Ross et al., 1984; Crosby, 1983). Recirculation of field return flows lengthens the residence time that the effluent remains on the farm and, as a result, allows for additional herbicide loss through volatilization and photolysis (Soderquist et al., 1977; Crosby, 1983) and adsorption to sediment (Ross et al., 1984).

The reuse of rice irrigation water in Heidrick Farms (as well as the other reclamation districts examined) did not appear to degrade irrigative water quality. Electrical conductivity did not exceed 1000 dS/m and therefore was suitable to support normal crop production (Maas, 1984). In addition, molinate residues were not detected in samples of corn, sugar beets, and tomatoes collected from Heidrick Farm at harvest (0.05 ppm molinate) demonstrating that none of the crops irrigated with rice return flows accumulated or retained molinate residues to harvest (R. Riggs, Stauffer Chemical Company, written communication).

In theory, the longer a farm continues to recirculate rice field return flows, the less herbicide residues will be present at the time the farm discharges to collector drains and sloughs. Heidrick Farms recirculated for a duration of 15 days after the last Ordram application and lowered molinate levels to <10 ug/l. However, since thiobencarb dissipates more slowly, and was applied later in the growing season, higher concentrations were measured in discharges to the Toe Drain after June 6. Based on the dissipation data presented in Figure 3, a recirculation period between three to four weeks would have lowered the thiobencarb residue levels to below 10 ug/l. It should be stressed however, that other farms would be expected to differ in the rate at which thiocarbamate residues dissipate from their drainage system. The minimum duration required to reduce residues to below the CDFG recommended guidelines (24 ug/l thiobencarb, 90 ug/l molinate) would depend on a variety of factors inherent to the farm drainage system including dilution capacity and ambient water temperatures. Additional studies are needed to evaluate the effectiveness of other versions of farm recirculation and impoundment systems such as the the use of "set-aside" acreage for temporary ponding and the examination of smaller scale recirculation systems which culture only rice.

Applying recirculation practices to entire reclamation districts growing rice, such as RD108, produces additional large-scale reductions in herbicide discharge. The effluent from approximately 20,000 acres of flooded rice fields was retained longer within the district through partial recycling and by utilizing nearly all of the storage capacity of the district drainage system (Granicher, written communication). The scope of this effort is evident by the large increase in the efficiency of water utilization during 1984 as compared with 1982 (Table 5). Undoubtedly, the lengthening of the mandatory field holding periods for Ordram and Bolero as well as recirculation led to the significant increase in the estimated residue retention times within the district. As a result of these water management measures, the fraction of molinate discharged (relative to the amount applied) decreased to under one-tenth the estimated 1982 level and for thiobencarb, approximately one-seventh the 1982 level (Table 4).

Although the diel sampling study demonstrated a statistically significant reduction in molinate concentrations over a 24-hour period, the use of daily composited samples instead of a single sample pair did not appear to significantly affect the mass discharge estimates. Composite water samples are recommended when estimating mass loading (USEPA, 1982). Assuming a linear decrease in residue levels, compositing grab samples collected at the time the pumps are initially switched on, and at the end of pumping, may correct for the reduction in forebay concentrations due to plant operation. In addition, due to the lack of analytical precision near the detection limit of thiobencarb, a detection limit less than 1.0 ug/l is more appropriate when comparing seasonal peaks to the CDHS secondary drinking water action level of 1 ppb.

Other rice growing districts besides RD108 appear to have the capability of increasing water utilization; this was evident during the 1977 drought year. Return flows from the Colusa Basin Drain, Butte Slough Outfall, as well as RD108 were curtailed to exceptionally low levels in an effort to conserve water (USGS, 1978; CDWR, 1978). Rice culture in low flow paddies has been demonstrated as a feasible method of growing rice in the Sacramento Valley (CDWR, 1982), and would complement efforts to intensively manage district and farm return flows through partial or full recirculation. Any reduction in irrigation diversions through these measures would have the added benefit of freeing additional water supplies to enhance fisheries, recreation, and navigation in the Sacramento River. As a result, a greater percentage of freshwater flowing into the Sacramento-San Joaquin Delta-Estuary would in fact be directly from reservoir releases rather than rice return-flows which have a lower water quality (i.e., higher levels of suspended solids and organic material) (Tanji et al., 1982). Moreover, rice chemicals such as thiobencarb, which are difficult to limit in their off-farm movement are best managed in recirculation systems. The introduction of new rice pesticides in the Sacramento Valley may ultimately depend on the development and acceptance of effective return flow management practices which limit residues from being discharged to the Sacramento River.

With the additional detection of molinate and thiobencarb in the Feather River drainages coupled with the monitoring results presented in Finlayson and Lew (1984), there is now evidence that molinate and thiobencarb are discharged from every major rice growing area in the Sacramento Valley. The districts east of the Feather River accounted for roughly 10 percent of the total molinate used during 1982 (Cornacchia et al., 1984) and are probably the sole source of molinate and thiobencarb released to the Feather River. Molinate was detected at trace levels (<3 ug/l) in the Feather River during this study, and by Finlayson and Lew (1983a) during 1982. It is interesting to note that during 1984, molinate and thiobencarb residues were found at highest levels (and with greater bioconcentration factors) in fish collected from RD1000 (this study), compared to fish collected from other areas of the Sacramento Valley such as the Colusa Basin Drain (Finlayson and Lew, 1984).

The movement of molinate residues as far downstream as Suisun Bay and as far south as the Mokelumne River system illustrates the fact that effluent from Sacramento Valley rice fields are a major input of pesticides to the Sacramento-San Joaquin Delta Estuary (Figure 7; Figure 8). Previous water quality surveys along the

Sacramento River by Finlayson and Lew (1983 a,b) and Cornacchia et al., (1984) reported molinate and thiobencarb residues between the towns of Colusa and Rio Vista. The highest concentrations were found between Colusa Basin Drain outfall and the Feather River, an area of the river which historically has had the lowest dilution of agricultural surface return flows during May and June. Sampling of the lower Sacramento River between Freeport and Rio Vista during 1983 and 1984 (this study) showed that there is little or no reduction of molinate levels over this stretch of the Sacramento River (Cornacchia et al., 1984).

Consequently, molinate residues from the Sacramento River can be expected to be carried southward into the central Delta and beyond when the gates of the Delta Cross Channel (DCC) are open for SWP and CVWP diversion. Detectable levels were found as far south as Little Potato Slough, a waterway connected with the lower San Joaquin River. An examination of the cross delta flow pattern during this period indicates that delta flows moved in a southerly direction from Little Potato Slough (CDWR, 1984). Reverse (upstream or southerly) flows occurred in the Old and Middle Rivers on May 29 (-5,067 cfs average net flow). Based on this flow observation and previous dye distribution studies conducted by CDWR (1967), it is likely that detectable levels of molinate would be found further south in the lower San Joaquin River system between Little Potato Slough and the Clifton Court forebay. In fact, studying the distribution of molinate residues between the DCC and the Clifton Court forebay while the SWP or

CVWP pumps are in operation may provide useful information concerning cross delta water movement.

Inflows from Miner and Steamboat Sloughs, as well as from the main stem of the lower Sacramento River appear to be the sources of molinate residues detected in the Cache Slough system. A decreasing concentration gradient was observed from Rio Vista (high end) to upper Cache Slough suggesting that residues were moving upstream through tidal action or entrained by upstream pumping. A similar concentration gradient was observed in 1983, however, the Toe Drain rather than sources further downstream appeared to be the primary source of herbicides entering Cache Slough (Cornacchia et al., 1984). It is important that future sampling for rice herbicides in the northern Delta should further elucidate the relative contribution of agricultural by-products into the Cache Slough from the Toe Drain, the Sacramento River, and Miner and Steamboat Sloughs.

Of potential biological concern is the detection of molinate as far west as Susuin Bay (Chipps Island). The Suisun Bay region supports a diversity of estuarine species and serves as a nursery area for the developing young of a number of important species including the striped bass, white sturgeon, and the opossum shrimp (see review in Cornacchia et al., 1984). Fortunately, the highest concentration of molinate found was below levels which are known to adversely affect aquatic life. However, if the discharge of thiobencarb to the Sacramento River should increase in the future, the potential chronic exposure could be toxic to the opossum shrimp, *Neomysis mercedis* (Cornacchia et al., 1984). Work is currently underway by SWRCB to estimate the joint chronic toxicity of molinate and thiobencarb on the reproduction and growth in *N. Mercedis*.

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