Small-scale rectangular plots at Davis are being used to determine how long chemicals applied in rice fields persist in flood and seepage waters, where the chemical residues go, and how fast they get there. This article presents data from some dye tracer experiments using two chemical application techniques (uniform application on the water surface and slug injection at the point of water inflow) and three water management practices (static, flow-through, and recycled systems). The distribution, persistence, and movement of a rhodamine dye tracer in flood waters was found to be greatly affected by these different water management systems.

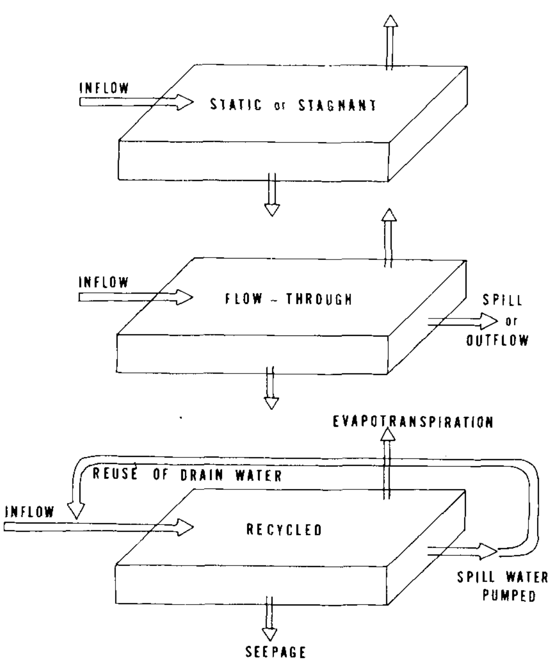
DYE TRACERS AID RICE CHEMICAL RESIDUE STUDIES

K. K. TANJI

M. MEHRAN

J. W. BIGGAR

D. W. HENDERSON



Experimental water management systems used in tests for chemical residues in rice.

TO DETERMINE the fate of herbicides, fertilizers, and other applied chemicals in flooded rice culture, strip plots 7.6 m x 61 m (25 ft x 200 ft) under different water management systems have been established at UC Davis. Water-applied and soil-incorporated chemicals are being followed closely to determine where they move and how long they last in flood waters and submerged soils. The objective of this investigation is to develop potential scientific and management solutions to maximize the effectiveness of chemicals applied in rice fields, and, at the same time, minimize the presence of their residues in the irrigation return flows. These management solutions will be needed if water quality standards and discharge requirements in rice growing areas become more stringent in the future.

This report is the first of three articles summarizing three years of data (1970–72) on the fate of applied chemicals in flooded rice fields. The present report contains dye tracer experiments to determine water-flow patterns and chemical distribution, persistence, and movement in flood waters for different water-application methods and management practices. Future reports will contain data on Molinate (Ordram), a herbicide, and ammonium sulfate, a nitrogen fertilizer.

Three practices

The sketch describes the three water management practices under investigation. In the static system there is no spilling of flood waters and only enough irrigation water is applied to replenish losses due to evapotranspiration and seepage. In the flow-through system some flood waters are continuously spilled. The recycled system is similar to the flow-through system except spill waters are recirculated back to the inflow end, mixed with fresh irrigation water, and then reused. Thus, for the static and recycled systems there is no surface drainage outflow from the rice fields. For these water management studies flood water depth was kept at 8 to 10 cm (3 to 4 inches), and inflow, outflow and recycled waters

Flood water sampling equipment for chemical residue tests with dye tracers in rice.

were metered throughout the growing season. The test strips had a slope of about 0.15% in the direction of flow.

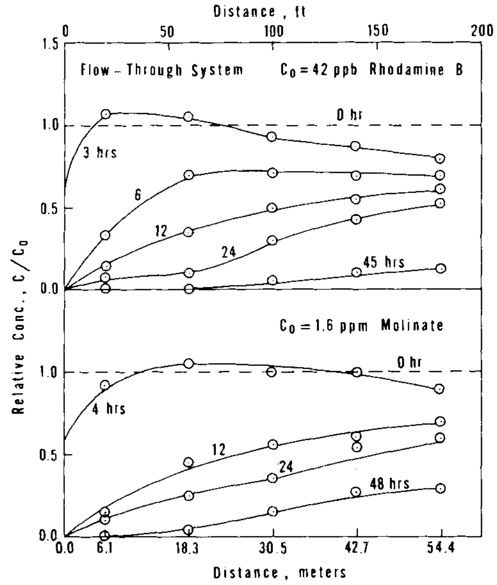
Chemical treatments imposed on the strip plots involved fertilizers and herbicides applied pre-flood mixed into the soil, or post-flood sprayed or broadcasted into the water. Chemical residues in flood and seepage waters (percolating soil solutions) were followed closely. Flood water sampling equipment consisted of aluminum pipe booms spanning the width of the plots. Attached to each boom were 12 lines of plastic tubing, one end immersed about 2.5 to 5 cm (1 to 2 inches) below the water surface at 61 cm (2 ft) intervals and the other end connected to a plexiglass sampling box as shown in the photograph.

When this sampling box is placed under vacuum, flood water samples are obtained from 12 sampling points across the width of the plot. A total of five cross-section booms are installed for each plot at 6.1 m (20 ft), 18.3 m (60 ft), 30.5 m (100 ft), 42.7 m (140 ft), and 54.4 m (180 ft) from the water-inflow end. Seepage waters are sampled with porous clay filters buried horizontally at the 5 cm (2 in), 20 cm (8 in), and 40 cm (16 in) depths in the submerged soil. Each filter is connected by plastic tubing to a sampling flask. Soil solutions are extracted when the flask is subjected to vacuum. The flood and seepage waters are collected as frequently as desired, and are subjected to many chemical analyses.

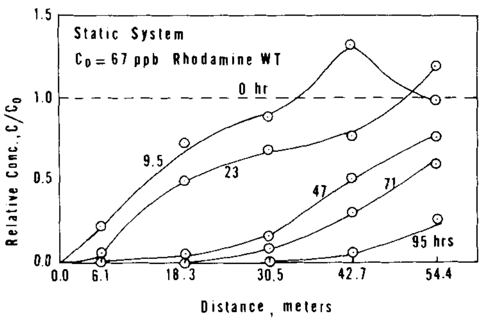
Graph 1 shows a comparison of distribution, persistence, and movement of a dye tracer (Rhodamine B) and Molinate (Ordram 6E) in a flow-through system. These chemicals were mixed together and sprayed as uniformly as possible on the water surface of a flooded strip plot containing no vegetation. For this flow-through system flood water spilled at the lower end (61 m) was about 30% of the inflow rate at the upper end (0 m). The estimated time of travel of water over the length of the plot was about 56 hours with flow velocities highest at the inflow end and decreasing with downstream travel. Each data point represents the average concentration of 12 cross-sectional water samples from a given sampling station. The curves connecting these data points give the longitudinal distribution of the chemical at different time intervals after application.

The chemical concentration unit is reported as relative concentration, C/C_0, where C_0 is the average initial concentration of the chemical in the flood water shortly after application and C is the concentration at any time after application. Relative concentration can also be interpreted as a decimal fraction of the chemical still present at particular sampling stations, at different times. Thus, a C/C_0 value of 0.5 means the chemical concentration is half or 50% of the original concentration. Using relative concentrations, it is possible to directly compare two chemicals of different initial concentrations which are given by the C_0 values in graph 1.

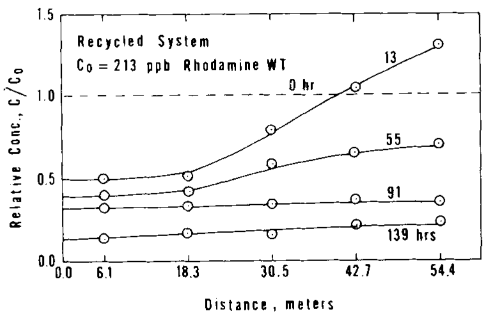
Because water depth was held constant in these studies, fresh irrigation water was continually introduced at the upper end 0 m) to compensate for water losses due to seepage (about 2.5 cm per day)



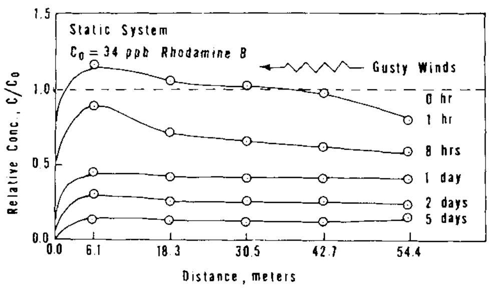
Graph 1. Comparison of dye and herbicide distribution for various times after uniform spraying flood water (flow-through system).



Graph 2. Dye tracer distribution for times after uniform spray application (static system).



Graph 3. Dye tracer distribution for various times after uniform spray application in a recycled system.



Graph 4. Impact of wind-action on dye distribution in a static system for winds gusting against direction of water flow.

and evapotranspiration (about 0.7 cm per day), and outflow (about 1.6 cm per day) for the flow-through system. (Seepage losses at Davis are higher than most rice-growing areas primarily because the soil is of lighter texture.) With this inflow of fresh water, chemicals applied on the water surface (0-hr, dotted horizontal line) are displaced downstream.

At the same time, the chemical increases in concentration due to the concentrating process of evaporation, i.e., pure water is lost to the atmosphere leaving the chemical in the flood water. On the other hand, the chemical concentration decreases due to seepage, degradation, sorption, and gaseous escape. As shown in graph 1, the net result is a downstream displacement of the chemical and decrease in chemical concentration with time. It should be noted that Rhodamine B, a pinkish fluorescent dye, behaves very similarly to Ordram 6E, a liquid form of Molinate, so the results of dye tracer studies indicate what may happen to this particular herbicide.

Rhodamine WT

Graph 2 gives a similar plotting of data for Rhodamine WT (a dye tracer similar to Rhodamine B, but subject to less sorption losses) uniformly sprayed on the water surface in a static or stagnant water management system. Because water depth was held constant, fresh water was introduced into this plot to only replenish the 3.2 cm per day of water loss due to seepage and evapotranspiration. It shows that this dye tracer persisted longer in the flood water than previously (graph 1) because there was no spill of flood water, and hence smaller inflow of fresh water. The average time of travel of water for 61 m was about 90 hours for this test run. Unlike data from the flow-through test shown in graph 1, graph 2 and graph 3 contain data in which the dye tracer was sprayed on the plots after a canopy of rice was established.

Graph 3 presents persistence and movement data for a recycled system in which spill water (30% of inflow rate) was recirculated back to the inflow end. The inflow rate of fresh water was about the same for the static system, 10.6 liters per minute (2.8 gpm for 0.115 acre or 5.4 cfs per 100 acres). It shows that the dye tracer persists longer than in the flow-through system (graph 1) because there is no spill of flood waters, and, moreover, is more uniformly distributed than the static system (graph 2). For example, in the flow-through system only a trace of dye was present 45 hours after application, and in the static system it was present only in the bottom half of the plot 47 hours after application. In the recycled system, the dye was uniformly distributed throughout the length of the plot from about 55 hours after application and longer. Data from graphs 1 and 2 indicate that no matter how uniform a chemical may be applied on a water surface its distribution can be markedly affected by downstream water movement unless recirculation is practiced.

Wind

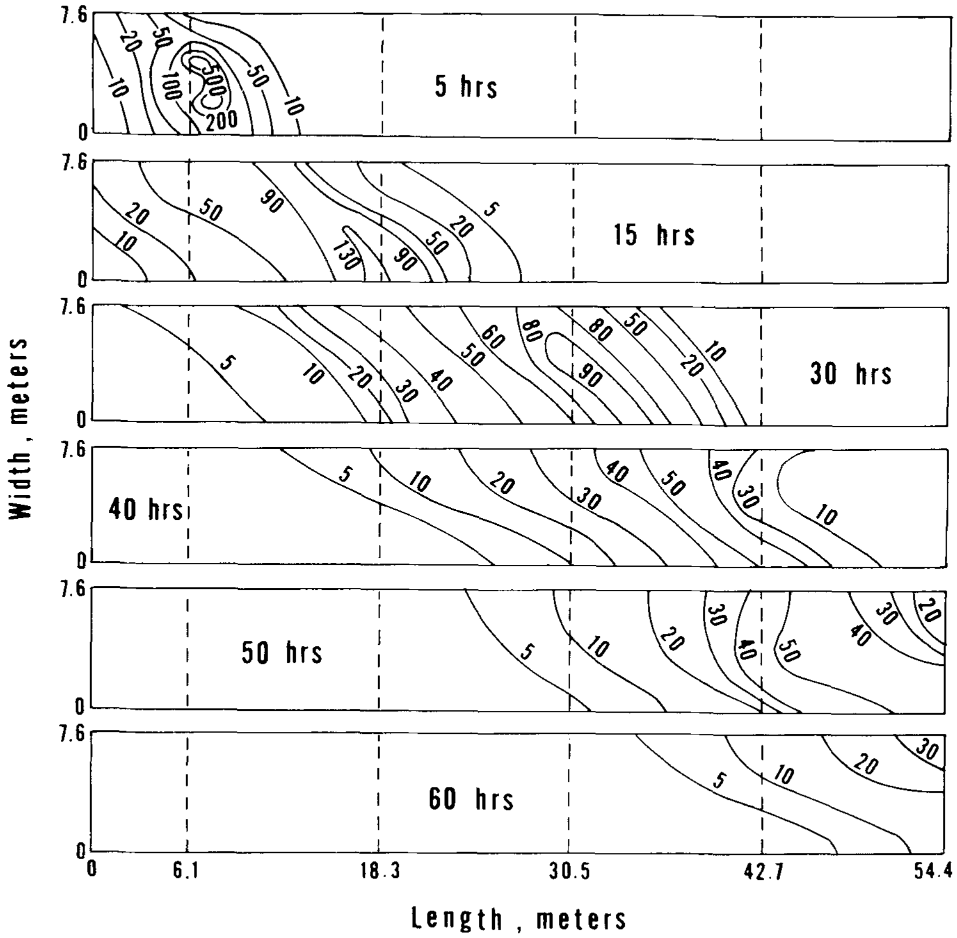
The effects of wind direction and velocity may also modify chemical distribution in flood waters. Graph 4 shows (for a static system) the impact of winds gusting up to 13.4 miles per second (30 mph) against the direction of water flow. Unlike the data shown in graph 1, the Rhodamine B was uniformly distributed because water waves up to 7 cm high moved the chemical upstream against the normal flow of water. This mixing and redistribution of chemical by wind action did not occur in another companion plot similarly sprayed, but with a rice plant canopy above the water surface. The presence of a plant canopy acted as a barrier and prevented such wind-action effects.

In another type of dye tracer study, a slug of Rhodamine WT was injected for about an hour at the inflow end of a flow-through plot, followed by inflows of fresh irrigation water. Graph 5 shows a series of dye distribution patterns for different times after injection. It gives a top view of dye distribution looking down at the water surface in contrast to the average cross-sectional data given in the previous graphs. The lines shown in graph 5, are lines of equal die concentration similar to contour lines shown on maps to represent land surface elevations. Five hours after injection, the slug of dye began to spread as it moved downstream. A peak concentration of 500 ppb was located at about 6.5 m from the inflow end, with a sharp front and tail of dye at lesser concentrations.

Thirty hours after injection the dye front was at about 42 m, the peak concentration of 90 ppb was at about 30 m, and there was a long trailing tail back to nearly the inflow end. Fifty hours after injection the trailing edge of the dye was located between 20 and 30 m, the peak concentration of 50 ppb was between 42 and 54 m, and the front was passing beyond the last sampling station at 54.4 m, and into the drain. The average time of travel of water for 61 m was about 60 hours.

Time

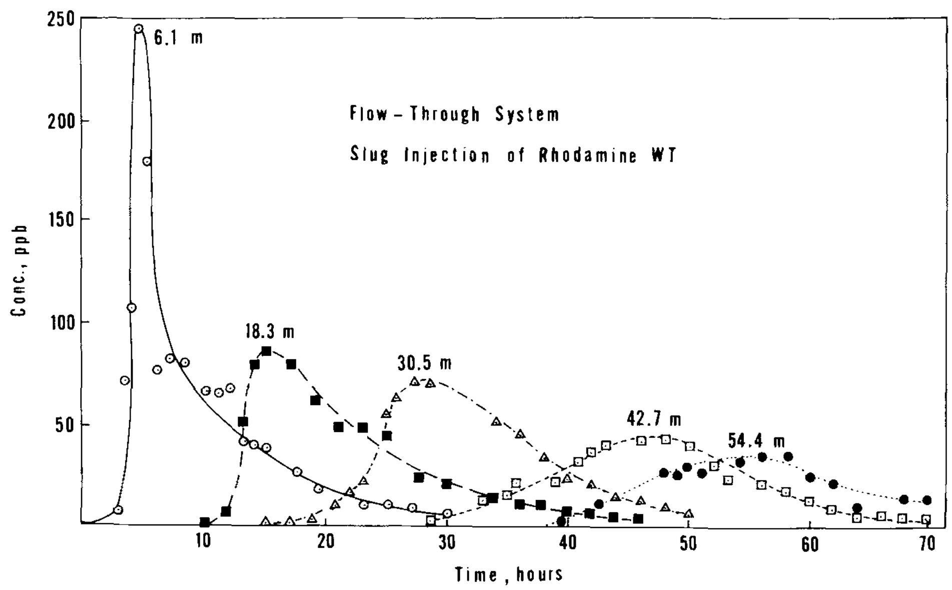
Graph 6 plots the same data presented in graph 5, but with the average cross-sectional concentration of the dye plotted against time for 5 sampling stations. It shows that the slug of dye first reaches the 6.1 m station about three hours after injection, rises rapidly in concentration and peaks at about five hours, drops off rapidly, and then tails off for about 30 hours. Meanwhile the front of this dye has approached the 18.3 m station at about 10 hours, peaks to a high concentration of about 100 ppb 15 hours after injection, and then drops off to lower concentrations for about 45 hours. Graph 6 shows that the peak concentration of this dye decreases more or less exponentially with distance downstream and the slug tends to spread out in time with initially a sharp front at the 6.1 and 18.3 m stations, and more or less symmetrical front and tail at the 42.7 and 54.4 m stations. It should be noted that this kind of chemical movement pattern in overland flow of water is not unique, for similar types of curves are obtained when a slug of chemical is applied on a surface of a wetted soil profile and leached downward with irrigation water.



Graph 5. Time and spatial distribution of a slug injection of dye tracer at the inflow end of a flow-through system.

Future research

These two types of dye tracer studies—uniform application on water surface and slug injection—have provided much information and data on water flow patterns and chemical transport in flooded rice culture with rectangular geometry and under different water management practices. Future reports will contain pre-flood, soil incorporation and post-flood, water-applications of Molinate and ammonium sulfate.



Graph 6. Plottings of average cross-sectional concentrations for various times at different sampling stations for a slug injection of dye tracer in a flow-through system.

K. K. Tanji is Lecturer in Water Science and Specialist; M. Mehran is Postgraduate Research Water Scientist; J. W. Biggar is Professor of Water Science and Water Scientist; and D. W. Henderson is Professor of Water Science and Irrigationist, University of California, Davis. D. T. Bradley, Superintendent of Cultivations; M. Ashkar and M. Iqbal, Staff Research Associates; and J. Martin and J. Corry, Jr., Laboratory Helpers also assisted on this investigation. *This project is being supported by the California Rice Research Foundation.*