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A N N U A L R E P O R T

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TITLE: PREDICTING HYDRAULIC CHARACTERISTICS OF CRITICAL-DEPTH FLUMES OF SIMPLE AND COMPLEX CROSS-SECTIONAL SHAPES

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: Ariz.-WCL 72-1

INTRODUCTION:

The broad-crested weir style flume appears to be well suited to irrigation canal applications. The errors of construction are easily controlled because the width is wide enough to make the usual variations in canal-construction dimensions unimportant, while the flow depths are deep enough to absorb the error of gage placement, which is done with surveying techniques. Publicity has been widespread, and we have received requests for information and assistance from farmers, researchers, university faculty members, Soil Conservation Service offices, concrete-ditch contractors, and numerous foreign inquirers. Requests have come from almost every western state, Canada, India, Sri Lanka, Puerto Rico, and the Netherlands where a design for a small flat gradient river was proposed. Standard flume sizes have been developed for several small size canals, which will be published in a USDA Farmers' Bulletin, with a more technical version being prepared for Transactions, ASAE. We plan to extend these standard flumes to larger sized canals and laterals. The present versions are computed for trapezoidal canals with 1-ft-bottom widths and 1:1 sideslopes. Two-ft bottom canals with 1:1 and 1.25:1 are also included.

The Salt River Project now has the ability to design this style of flume. Three large flumes were designed by Joe Robins (SRP), and the designs were reviewed by us for laterals in their canal system. These were installed in October 1978 near Gilbert, Arizona.

The mathematical model with the laboratory ratings that have been accumulated over the last 10 years, including some work by Bazin in 1865 and by A. R. Robinson in 1968 (as updated by Humpheries and Bondurant, 1978), were presented at an IMEKO meeting in the Netherlands (FLOMECO 78). The modeling was well received, and contact was made with M. G. Bos who has also done research with long-throated

flumes. Contact was also made with W. R. White who has been working with Crump weirs. The significant property of these weirs is their apparent favorable characteristic of transporting sediment because of the sloping approach ramp. Since our broad-crested weir style flume has similar properties, it should also pass sediment well. It has performed satisfactorily in irrigation situations with low-sediment transport rates. We may be able to observe the field behavior in more detail at some of the many locations resulting from the contacts for assistance and information. A list of five publications and one presentation concerning flumes is attached.

NEW DESIGNS:

Several portable flumes and "expedient" flumes were conceived and designed during the past year. Three sizes of furrow flumes have been designed, all of the sill style. Two sizes were constructed in three copies each. The first, with a sill width of 6 inches, has a flow range of about 3 to 225 gpm, and was delivered to Guy Dickey, SCS, Davis, California, for evaluation in field use. The second constructed size was a metric version with a flow range of about 0.15 to 12 liters per second (2.5 to 190 gpm) and had a 10-cm sill width. The third size is a smaller version with an upper limit of about 35 gpm. It will have a throat width of 5 cm.

The major advantages of these constructions are their relative insensitivity to soil swelling, accidental bumping, and precision leveling. These features are accomplished by locating the stilling well as closely as practical to the elevation zero reference surface of the sill. The pressure intake tapping is still located upstream, as usual.

"Turtle" Flume. The "turtle" flume, designed for the Soil Conservation Service is to be constructed in two sizes: the standard size as reported last year, and a longer version with an 18-inch-long throat instead of the original 12-inch-long throat because of the need to measure larger, and thus deeper, flows in canals having 1:1 sideslopes and 1-ft bottom widths but constructed 36 inches deep. The original version was limited to canals less than 30 inches deep. A patent application was filed in August 1978.

"Expedient" Flumes. Of the "expedient" flumes, one in particular appears useful. It is constructed from a single sheet of 3/4-inch plywood. One method of construction is as follows:

1. Cut off and save a 12.0-inch-wide piece from one end of the full sheet. (Result is a 12.0-inch by 48-inch piece to be used later for the sill piece and ramp section.)

2. Cut two more pieces about 2 inches wide, also from the end of the full sheet. (Result is two pieces, 2 inches by 48 inches, to be used later as cross ties for the flume.) These are optional and can be replaced with other strip materials.

3. The remaining large piece which is about 48 inches by 80 inches long is centerline marked along the long dimension and sawed lengthwise parallel to the centerline but offset one-half plywood thickness (3.8-inch). (Result is one piece 24-3/8 inches wide by 80 inches long and one piece 23-5/8 inches wide by 80 inches long that will be nailed together to form a "V" trough shape with an inside edge top width of 33.41 inches.)

4. Nail the two large pieces together, observing that the wider piece is properly overlapped and is used to start the nailing process. This overlap will make the flume top level when properly completed.

5. Nail the two 2-inch bracing strips as cross ties to the flume. They can be placed about 1 ft from either end of the "V" construction. Make sure that the "V" is 90° before nailing on cross ties. The measured top width should be 33.41 inches.

6. From the 12-inch-wide section cut two pieces: one rectangular 12.0 inches wide by 18 inches long, and the other 12 inches wide and about 19 inches long.

7. Bevel the two long edges of the 18-inch piece at 45°. This will become the sill crest piece. Nail in place flush with one end of the "V" section, so that it is symmetrically placed to form an elevated floor in the "V" section.

8. Make a centerline lengthwise on the 19-inch-long piece. Mark from the corners of one end to the centerline at the other

end to form an isosceles tringle with a 12-inch base and a 19-inch altitude. Saw out the triangle. Bevel the long sides at about 43-1/2° for the entire length. Bevel the 12-inch side at about 18.4°, so that it will fit the upstream face of the previously installed sill piece. Nail triangular ramp section into place.

9. The readout is best made with the portable stilling well and probe system previously reported (see Annual Reports for 1975-1977), although a wall-mounted gage can be used.

10. Use plastic sheeting attached to the upper end of the flume to aid in water sealing.

This flume was demonstrated in an earthen canal where it was installed by a class of college students during the hydrology summer camp programs of the University of Arizona. It was quickly built (two people less than 30 min) and quickly installed (several class members in about 15 min). Readout was made with the stilling-well cup, portable-pipe-and-siphon-hose sensing mechanism used on many of our previous portable flumes. The rating table was calculated by computer modeling, and is shown in Table 1. Figure 1 shows a layout, similar to that described, but in metric notation and with no overlap allowance for nailing the two large pieces together. This flume design has been proposed for portable low-flow stream monitoring in Nebraska.

Concrete Pre-Cast Flumes. Special molding pans were built to make the ramp and sill flumes as two pre-cast parts, a sill section and a ramp section. The concrete thickness is basically 1-1/2 inches with edge thickening to 4 inches. Reinforcing mesh and steel are placed in the blocks. They weigh about 90 pounds each for the small canal (1:1 sideslopes and 1-ft bottom width) and correspond to the 1-ft-high standard flume that we proposed for the Farmers' Bulletin. Larger sizes appear to be impractical because special equipment would need to be used. Sheet steel versions are planned for the larger sizes, but have not been designed in detail. Side wall gages complete these flume systems.

Earthen Canals. Many canals are unlined. Application of simple construction techniques to these is progressing. The series recommended for lined canals can be used with a short length of pre-paved canal section, and was proposed for applications in northern California, Oregon, Montana, and Nevada. However, unlined canals are usually wider and shallower, often resembling "waterway" construction rather than irrigation canals. These shapes will require a different series of sizes than those presented for lined canals. The Bureau of Indian Affairs plans to install some during the spring of 1979, and has selected several sites for design and application.

The unlined storm flow channels in Florida, that were fitted with flumes on 3-6 May 1977, were visited in October 1978. They appear to be functioning satisfactorily hydraulically; however, the concrete is being attacked by the acid drainage waters and has deteriorated to the point that plaster-patch repairs to the throat section have had to be made. It appears that limestone aggregates in the concrete mix are being dissolved.

SUMMARY:

Error control concepts for the sizing of the broadcrested-weir style of flume single it out as a very usable shape for lined canals. Because of this, precomputed sizes suitable for three common concrete slipformed canals have been selected and computed in cooperation with Soil Conservation Service analysis of needs. These have subsequently been slightly modified to incorporate field experience, and edited for a USDA SEA Farmers' Bulletin to be distributed nationwide.

Comparisons of mathematical modeling results and laboratory and field measurements were published for 18 flumes of triangular, trapezoidal, and rectangular cross-sectional shapes, including trapezoidal broad-crested weirs. Representative data for weirs and flumes previously published by Bazin (1865) and by Robinson (1968, as updated by Humpheries and Bondurant, 1978, private communication) include stage-discharge information on each flume, so that further analysis by interested scientists is possible.

A series of three small flumes, two of which have been constructed for field testing during the coming irrigation season, have been developed for furrow irrigation studies, at the request of the Soil Conservation Service, a California university, and groups within our own agency. Advantages are ± 2% accuracy with easy field installation and insensitivity to movement of the flume due to settling or accidental bumping. Special but simple physical arrangements involving the translocation of the stilling well provide this feature that is part of mechanisms for which a patent application has been filed (August 1978).

An inexpensive flume, made from one sheet of plywood and some plastic sheeting or irrigation canvas, was demonstrated to a university hydrology class, and subsequently is being considered for portable use in Nebraska for surveying low-flow stream discharges.

The concrete 3-section triangular flumes installed in Florida forestry watershed projects continue to function to their satisfaction. Some concrete quality problems related to the acid runoff is apparent.

Design recommendations for a concrete sill-type of flume were made for a special site in the Netherlands for use in a flat gradient small river.

Semi-portability for the concrete canal versions was achieved in the form of two precast concrete blocks, a sill, and a ramp section for use in small, 1-ft-wide trapezoidal canals for flows up to 10-12 cfs. While not portable, they can be moved and reinstalled.

PUBLICATIONS:

1. Clemmens, A. J., and J. A. Replogle. New flume breakthrough for ditch irrigators. Irrigation Age 12(7):82-88. April 1978.

2. Clemmens, A. J., and J. A. Replogle. Constructing simple measuring flumes for irrigation canals. USDA Farmers Bulletin (In press).

3. Replogle, J. A. Flumes and broad-crested weirs -- Mathematical modeling and laboratory ratings. Flow measurement of fluids. H. H. Dijstelbergen, and E. A. Spencer (eds). North Holland Pub. Co., Amsterdam, New York, Oxford. pp. 321-328. 1978.

4. Replogle, J. A., and A. J. Clemmens. Measuring flumes of simplified construction. Presented at 1978 winter meeting of Amer. Soc. Agr. Eng., Chicago, Illinois, 18-20 December. Paper No. 78-2506. (Multilithed copies available).

5. Replogle, J. A., and A. J. Clemmens. Broad-crested weirs for portable flow metering. Trans. Amer. Soc. Agr. Eng. (Accepted for publication).

6. Replogle, J. A., H. Riekerk, and B. F. Swindel. Flow metering flumes monitor water in coastal forest watershed. Water and Sewage Works Journal 125(7):64-67. July 1978.

PERSONNEL: John A. Replogle, Albert J. Clemmens

Table 1. Calibration for plywood temporary flume.

Metric		English	
Y_1 Depth cm	Q Discharge L/s	Y_1 Depth ft	Q Discharge cfs
2	1.400	0.05	0.0314
3	2.75	0.10	0.0996
4	4.45	0.15	0.1966
5	6.48	0.20	0.321
6	8.86	0.25	0.475
7	11.59	0.30	0.657
8	14.65	0.35	0.869
9	18.08	0.40	1.113
10	21.87	0.45	1.388
11	26.04	0.50	1.696
12	30.6	0.55	2.04
13	35.5	0.60	2.42
14	40.9	0.65	2.83
15	46.6	0.70	3.28
16	52.8	0.75	3.77
17	59.3	0.80	4.30
18	66.3	0.85	4.87
19	73.8	0.90	5.48
20	81.7		
21	90.1		
22	98.9		
23	108.2		
24	118.0		
25	128.2		
26	139.0		
27	150.2		
28	162.0		

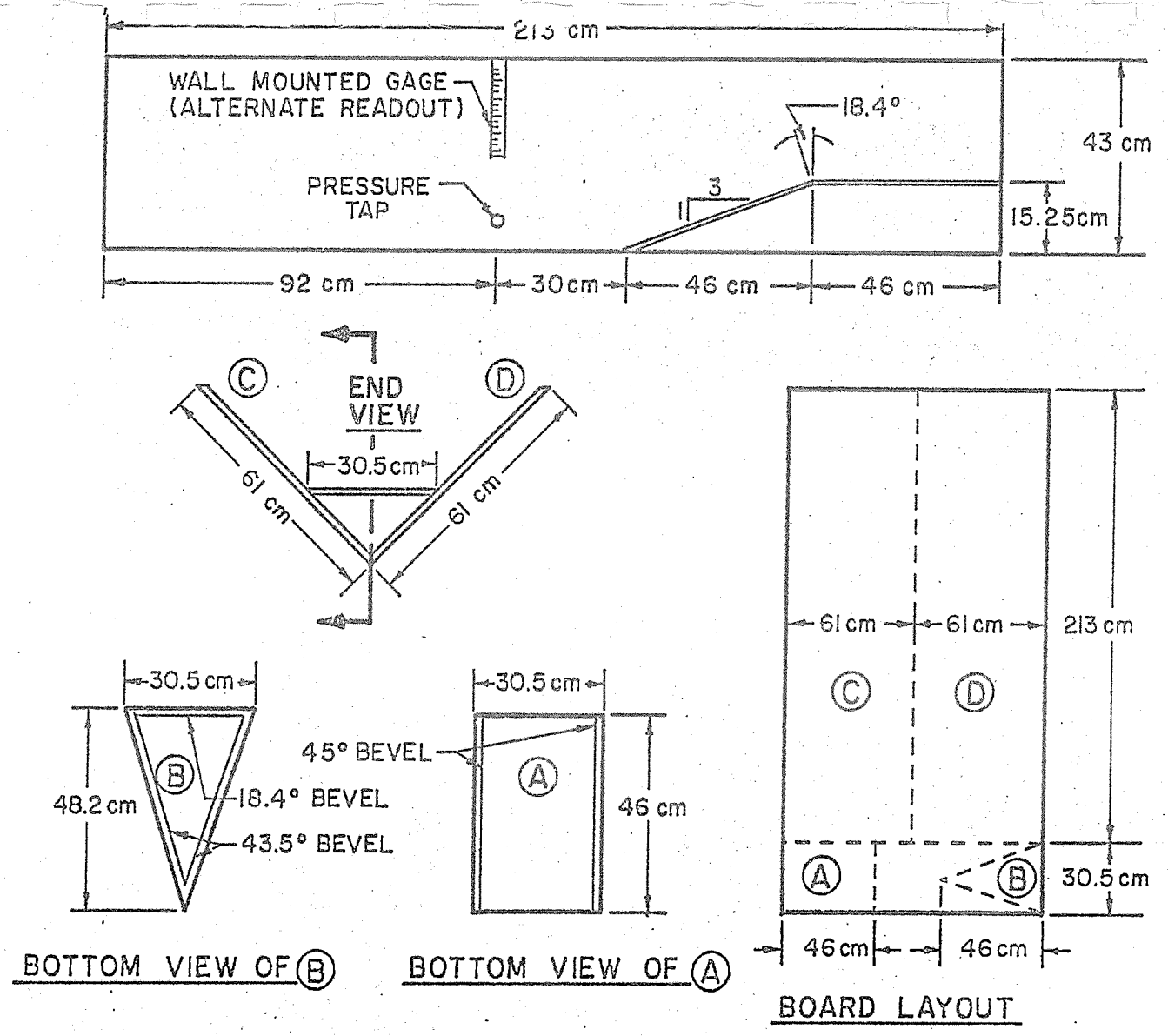
213 cm
WALL MOUNTED GAGE
(ALTERNATE READOUT)
18.4°
43 cm
PRESSURE
TAP
3
1
15.25cm
92 cm
30cm
46 cm
46 cm
C
D
END
VIEW
30.5cm
61 cm
61 cm
30.5 cm
B
48.2 cm
18.4° BEVEL
43.5° BEVEL
BOTTOM VIEW OF B
30.5 cm
45° BEVEL
A
46 cm
BOTTOM VIEW OF A
61 cm
61 cm
213 cm
C
D
A
B
30.5 cm
46 cm
46 cm
BOARD LAYOUT

Figure 1

TITLE: EVALUATING TRICKLE IRRIGATION FOR CANTALOUPE PRODUCTION

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 73-3

INTRODUCTION:

The objective and need for this research project appeared in the U. S. Water Conservation Laboratory 1977 Annual Report. Procedures and results for the second year conducted at the Mesa Experiment Farm, Mesa, Arizona, are presented in this report.

FIELD PROCEDURES:

Spring. Irrigation treatments included two subsurface trickle practices (trickle to end of harvest and trickle to beginning of harvest), two irrigation frequencies (weekly and daily), and three irrigation quantities (1.0, 0.8, and 0.6 times consumptive use). These 12 treatments were replicated five times in a randomized-block design, with each plot being two beds wide and 70 feet long. The trickle irrigation system used was Reed's Bi-Wall, a double-chamber polyethylene tubing, having a 12-inch outside orifice spacing. The tubing was installed 6 inches deep and 1 inch away from the seed row. Adjacent to the trickle irrigation study was a furrow-irrigated border, 5 beds wide and 280 ft long. The furrow irrigation was used as a standard to check yield, fruit quality, and consumptive use.

Cantaloupe seed, Top Mark, was planted on March 30 on the east slope of north-south oriented beds. Water applications for germination were 2.3 and 2.9 inches, respectively, on the trickle and furrow irrigation plots. Because of early rains, an additional 0.9 and 1.1 inches of water were applied on April 11, just before plant emergence to reduce soil crusting. Also, soil compaction existed on the entire field from spring plowing under the abnormally wet moisture condition. Plants emerged on April 12 and 13 with an excellent stand resulting on all plots. After thinning of plants to a 12-inch spacing along the row on May 3, 1.5 and 2.3 inches of water were applied to the trickle and furrow treatments. The different water quantities applied by trickle irrigation were initiated on May 12 and were

calculated by multiplying 1.0, 0.8, 0.6 times an estimated consumptive-use rate for a weekly or daily irrigation interval. This rate was taken from a 4-year mean consumptive-use curve measured for cantaloupes at the Mesa Experiment Farm (1), with irrigations based on the entire surface area between plants. One half of the trickle-plot irrigations were terminated on July 2, whereas trickle irrigations continued until July 17 on the remaining plots. Furrow applications after thinning were 3.7 inches on June 1, 3.7 inches on 12 June, 3.7 inches on June 21, and 2.0 inches on June 30.

Fertilizer applications included 150 lbs/acre of ammonium phosphate (16-20-0), sidedressed over the field before planting; 85 lbs/acre of urea (46-0-0) after thinning on May 12, and 85 lbs/acre of urea after early runners on June 1 for both methods. After the preplant application, fertilizer applications for the trickle were delivered through the system, whereas fertilizer applications for the furrow were banded about 2 inches away from the plant row. The total fertilizer applied was 102 lbs of actual N per acre and 30 lbs/acre of P_2O_5.

Principal data obtained included water applied, soil-moisture content by gravimetric and neutron probe measurements (the neutron information has not been fully analyzed), yield, and fruit quality. Water applications for the trickle treatments were measured with a turbine-vane water meter, after the water was filtered through a sand (#20 silica) filter and 200-mesh (75 micron) screen filter. Furrow irrigations were measured by an impeller-type water meter.

Cantaloupe harvest from 50 ft of the west row on the 60 trickle and 6 furrow plots began on June 30 and lasted until July 26 (27 days). Melons were harvested three times per week, sized, counted, and graded as marketable or culls. Four sizes were packed: 23, 27, 36, or 45 jumbo melons per commercial crate (22 x 13 x 13 inches) and were referred to by their sizing numbers. The smaller the number, the larger the melons, with the 36's generally the most desirable. All melons smaller than 45, rotten, soft, ground spot, slick, or split were considered the culled or discarded melons. At five

different times during the harvest period, four mature melons were selected at random from each plot. Fruit quality in terms of soluble solids, general appearance, netting, outside color, flesh color, flesh firmness, cavity dryness, cavity length, and cavity width were evaluated on these melons. Soluble solids were determined by a hand refractometer from the juice of a 1 cm^3 core from the blossom end of each test melon and at a location opposite the side where the melon laid in the field. General appearance, netting, outside color, flesh color, flesh firmness, and cavity dryness were judged subjectively by comparing cut surfaces to a pre-established series showing the variation of melon quality. Cavity length and width were measured with a hand ruler. Yield and quality data were analyzed statistically, and means were separated by Duncan's multiple range test.

Fall. After the harvesting of spring cantaloupes while subsurface trickle lines remained in place, old vines were removed using an onion knife that was mounted to a tractor tool bar to cut off vine tops from roots, followed by hand raking tops into the furrows; a rotary Lilisten cultivator was then used to prepare a seed bed; and fall cantaloupes were planted on July 31, within 5 days from final harvesting of spring cantaloupes. Trickle irrigation treatments, cantaloupe variety, water filtration, water measurement, thinning, and harvesting procedures were the same for the fall as the spring cantaloupes. The furrow-irrigated border was again used as a standard to check yield, fruit quality, and consumptive use.

Water applications for germination of 1.8 and 3.7 inches were applied to all trickle and furrow plots, respectively, on August 1. Plant emergence began on August 6; however, by August 9 a few seedlings had died or appeared to show salt damage on the trickle plots. Additional trickle irrigations of 0.9 and 0.7 inches of water were given on August 9 and 12, while soil salinity samples were taken along the plant row before irrigating on August 12. The young plants on the trickle plots appeared to recover and were about the same size as the furrow plants by thinning on August 23. After thinning, 0.5 and

3.3 inches of water were applied to all trickle and furrow treatments. Subsequent furrow irrigations were given of 3.7 inches on September 8, 3.3 inches on September 22, 3.6 inches on October 6, and 2.0 inches on October 20. The different trickle quantities (1.0, 0.8, and 0.6 times the estimated consumptive-use rate) and frequencies (weekly and daily) began on September 4 and continued to either harvest or the end of harvest. The 1977 consumptive-use curve measured for fall cantaloupes was used as a guide for scheduling irrigations.

Fertilizer applications included 150 lbs/acre of ammonium phosphate (16-20-0) banded 2 inches deep near the seed row on August 1 (before planting), 85 lbs/acre of urea (46-0-0) on August 23 (thinning), and 85 lbs/acre of urea on September 8 for both trickle and furrow plots. Cantaloupe harvesting began on October 18 and ended on November 9, lasting 23 days. Fruit quality samples were taken on three picking dates using procedures identical to the spring harvest.

RESULTS AND DISCUSSION:

Spring. The 1978 measured consumptive use was 18.2 inches of water for furrow-irrigated spring cantaloupes. This was nearly the same as the 4-year seasonal average of 19.1 inches determined by Erie et al. (1). A high water-application efficiency was obtained on the single furrow treatment, since the total water applied for the season was 19.4 inches. For the trickle treatments, the actual amounts of water made available for consumptive use, as calculated from the water applied plus rainfall, are shown in Table 1. The adjusted trickle irrigation quantities were 1.20, 0.97, and 0.77 times the 1978 measured consumptive use for the weekly and daily trickle until the end of harvest, and 0.98, 0.81, and 0.65 ratios for the weekly and daily trickle to the beginning of harvest.

Yields for spring cantaloupes are summarized in Table 2. Continuing to trickle irrigate until the end of harvest did not increase production or lengthen the harvest period over discontinuing to trickle irrigate at the beginning of harvest. As plant consumptive

use declined drastically (Figure 1), the additional water applied during harvest did not enhance plant growth. Ample soil moisture was present in the root zone to mature the melon crop where trickle irrigation stopped at harvest. Maximum cantaloupe production was obtained when the seasonal subsurface trickle irrigation quantity was nearly equal to the consumptive use under furrow irrigation. Results of 1977 cantaloupes showed that cantaloupe production did not further increase yields where trickle application exceeded the consumptive use by 25 or 50%. Marketable crates per acre decreased by 24 and 39% with applications at about 20 and 40%, respectively, below consumptive use; the total number of marketable melons larger than a size 36 declined by 29 and 53%; and the total number of marketable melons declined by 16 and 21% (all significant at the 1% level, Table 2). A trend of increased percentage of culled fruit resulted from the drier treatments, but the total number of culled fruit changed little with irrigation quantity (Figure 3). Spring production was not affected significantly by the two irrigation frequencies (Table 2). Marketable crates per acre were greater than 380 for both trickle and furrow irrigations with water applications near the consumptive-use requirement. Current commercial yields range from 150 to 250 crates per acre of spring cantaloupes in Arizona (2).

Table 3 shows that increased production at the optimum irrigation quantity was due to a greater number of larger 23- and 27-sized melons. However, the soluble solids (sugar percentage) improved for water applications at or below the consumptive-use requirement (Table 4). All the fruit-quality measurement (soluble solids, general appearance, netting, outside color, flesh firmness, and cavity dryness) were exceptionally good during the first week of harvest (Table 4). Fruit quality decreased during the second week of harvest, but the differences between treatments tended to be small (Table 5).

Figure 2 shows that about 75% of the marketable crates per acre for the optimum irrigation quantity were produced in the first 11 days of the 27-day harvest, and about 30% of the marketable crates

per acre were produced in the first 6 days, regardless of the irrigation quantity or frequency. After 6 days of harvest, marketable crates increased more for trickle quantities near the consumptive use than below. Relationships for total marketable melons were similar for crates per acre (Figure 3). The 100% production value represented about 1.5 fruits per plant, while 75% production would be 1.15 fruits per plant.

Fall. The measured consumptive use was 16.1 inches of water for furrow-irrigated fall cantaloupes. This was similar to the 1977 consumptive use of 15.8 inches used to schedule the irrigations in 1978. The adjusted trickle irrigation quantities, considering water applied plus rainfall, were 1.05, 0.86, 0.71 times the 1978 measured consumptive use for the weekly and daily trickle until the end of harvest, and 1.00, 0.81, 0.68 ratios for the weekly and daily trickle to the beginning of harvest (Table 1). On the furrow treatment, 16.6 inches of water was applied; and the consumptive-use ratio was 1.18

Fall cantaloupe yields are listed in Table 6. About 0.8 inches of rainfall occurred during the harvest period, and trickle irrigations to the end of harvest were not completed on a continuous basis. Therefore, results showed that yield differences between trickle irrigation throughout harvest and trickle terminated at harvest were small. However, marketable crates per acre decreased by 28 and 64%, where applications again were decreased by almost 20 and 40%; the total number of marketable melons larger than a size 36 decreased by 31 and 75%; and the total number of marketable melons decreased 7 and 19.7% (all significant at the 5% level). The reason for the greater percentage decrease for marketable crates and larger fruit than total marketable fruit was caused by a decrease in melon size and an increase in culled melons when less than the consumptive-use requirement was applied (Table 7). Weekly compared to daily subsurface trickle increased marketable crates per acre by 36% and increased the number of fruit larger than size 36 by 44% (both significant at the 5% level). No significant difference between the total

marketable melons per plot was recorded, while there was a trend of increased cull percentage for the daily over weekly trickle (Table 6).

Checking yields with the standard furrow irrigation method, the subsurface trickle produced fewer marketable crates per acre and marketable fruit larger than size 36; but the number of marketable fruit harvested per plot was similar for both methods (Table 6). Harvesting on the furrow plots was 2 to 3 days later than on the trickle plots, but lasted 3 to 4 days longer. Total production was lower in the fall than the spring, as expected; however, marketable yields were certainly respectable where the irrigation quantity was near optimum (2).

Table 7 indicates that the increased yield near the 1.0 trickle quantity and for weekly over daily was due to a greater number of larger melons, particularly the size 23 and 27. As the irrigation quantity decreased, the number of culls increased, although the number of green fruit remaining after harvest was less. Tables 8 and 9 show soluble solids to increase as the trickle irrigation quantity became less than 1.0. General appearance, netting, outside color, and cavity dryness did not decrease until the trickle quantity approached 0.6. Overall, the fruit quality was better during the first than the second week of harvest, while soluble solids were unchanged between weeks.

Approximately 75% of the total marketable crates per acre were produced in the first 14 days of the 23-day harvest on the optimum 1.0 trickle quantity (Figure 5). Again, about 30% of the marketable production was produced in about 6 days for both the 1.0 and 0.8 trickle quantity; however, the 0.6 quantity had lower yields during the entire harvest. After 14 harvest days, the 75% marketable melons represented about 0.6 of a fruit per plant, whereas the potential full-season harvest represented about 0.8 of a marketable fruit per plant in the fall with adequate water (Figure 6).

Winter. After the fall cantaloupe harvest, high-population carrots and dry onions were precision planted on December 12. The

bed was first flattened, cultivated, and two additional trickle lines were installed. Three trickle lines were spaced 25 cm apart at a 10-cm depth with a 100-cm top width on the bed. The east trickle line was the same used since April 1. Fifteen rows of carrots and onions were spaced 6 cm apart, while carrots were planted about 2 cm and onions about 5 cm along the row.

Subsurface over surface trickle offers several potential advantages for vegetable production in terms of less interference with thinning, cultivating, weeding, harvesting, replanting, or other field operations. Subsurface lines will not deteriorate rapidly from exposure to high temperatures or require staking during germination for protection against wind movement. Although chemical treatment of the irrigation water has not been used, root clogging has not occurred on the subsurface trickle lines to date.

SUMMARY:

Multiple cropping and minimum cultivation were used to evaluate the practical advantages of subsurface over surface trickle irrigation. Two consecutive cantaloupe crops were produced in 1978, and onions and carrots were planted in late fall. The same subsurface trickle system was used for all the crops, whereas surface trickle would have required removal and replacement of old or new trickle lines.

Maximum cantaloupe production was obtained with subsurface trickle applications near the consumptive use of about 18 inches in the spring and 16 inches in the fall. Marketable yields declined by 24 and 39% with applications at about 20 and 40% less than this optimum amount in the spring, while yield reductions were 28 and 64% in the fall. Water applications at 40% below consumptive use decreased considerably the fruit size and increased somewhat the soluble solids. Weekly subsurface trickle tended to increase yields over daily subsurface trickle, which was statistically significant in the fall and not in the spring. Regardless of the irrigation frequency or quantity, approximately 75% of the total potential

marketable melons were produced in the first 11 days of harvest in the spring and 14 days in the fall. Harvest lasted 27 and 23 days in the spring and fall, respectively. Continuing to trickle irrigate during harvest compared to discontinuing to trickle irrigate at harvest did not improve production. The best quality melons were picked during the first 7 harvest days, while optimum trickle and furrow irrigation productions were comparable.

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Table 1. Available moisture and adjusted quantities for trickle irrigation of spring and fall cantaloupes, 1978.

Practice	Irrigation treatment: Frequency	Irrigation treatment: Quantity	Water applied	Rainfall	Total available moisture for consumptive use	Adjusted irrigation quantity
	(days)	(consumptive-use ratio)	(inches)	(inches)	(inches)	(consumptive-use ratio)
			Spring Cantaloupes			
Trickle to end of harvest	weekly and daily	1.0	20.4[a]	1.5	21.9	1.20[c]
		0.8	16.3	1.5	17.8	0.97
		0.6	12.6	1.5	14.1	0.77
Trickle to beginning of harvest	weekly and daily	1.0	16.4	1.5	17.9	0.98
		0.8	13.2	1.5	14.7	0.81
		0.6	10.3	1.5	11.8	0.65
Furrow	variable	1.0	19.4	1.5	20.9	1.15
			Fall Cantaloupes			
Trickle to end of harvest	weekly and daily	1.0	14.6[b]	2.4	17.0	1.05[d]
		0.8	11.4	2.4	13.8	0.86
		0.6	9.1	2.4	11.5	0.71
Trickle to beginning of harvest	weekly and daily	1.0	13.7	2.4	16.1	1.00
		0.8	10.7	2.4	13.1	0.81
		0.6	8.5	2.4	10.9	0.68
Furrow	variable	1.0	16.6	2.4	19.0	1.18

a/ Based on the measured consumptive use of 21.4 inches for 1977 spring cantaloupes.

b/ Based on the measured consumptive use of 15.1 inches for 1977 fall cantaloupes.

c/ Based on the measured consumptive use of 18.2 inches for 1978 spring cantaloupes.

d/ Based on the measured consumptive use of 16.1 inches for 1978 fall cantaloupes.

Table 2. Summary of spring cantaloupe yields (mean of 5 replications), 1978.

Irrigation Treatment			Marketable crates per acre	No. of fruit[1/] per plot 36 and larger	Total no. fruit[2/] per plot harvested	Percent[3/] culls
Practice	Frequency	Quantity				
Trickle to end of harvest	Weekly	1.20*	434.0[ab]**	58.4[a]**	81.0[bc]**	8.3[a]**
		0.97	306.5[def]	38.0[de]	65.4[f]	10.7[ab]
		0.77	264.7[ef]	29.0[efg]	64.0[f]	14.9[abcd]
	Daily	1.20	436.3[a]	59.6[a]	87.4[ab]	12.3[abc]
		0.97	345.2[cd]	44.6[bcd]	74.0[cde]	12.9[abcd]
		0.77	248.3[f]	24.8[g]	65.6[f]	19.7[cd]
Trickle to beginning of harvest	Weekly	0.98	377.1[bc]	50.6[abc]	76.2[cd]	15.1[abcd]
		0.81	313.2[de]	39.4[cde]	70.4[def]	13.9[abcd]
		0.65	258.4[ef]	27.2[fg]	68.8[def]	20.3[cd]
	Daily	0.98	418.3[ab]	54.8[ab]	90.6[a]	16.6[bcd]
		0.81	297.6[edf]	36.8[def]	71.2[def]	17.7[bcd]
		0.65	247.0[f]	24.2[g]	67.0[ef]	21.1[d]
Furrow	Variable	1.15	381.2	51.3	79.5	12.4

*Ratio of seasonal consumptive use of 18.2 inches measured on furrow irrigation plots.

**Means followed by the same letter belong to same population at the 5% level of significance.

1/ Melons of size 23, 27, and 36 are included (Table 3).
2/ Melons of size 23, 27, 36, and 45 plus culls are included (Table 3).
3/ Number of culled fruit divided by the total number of fruit per plot harvested, expressed as a percentage.

Table 3. Grading of spring cantaloupes (mean of 5 replications), 1978.

Irrigation Treatment			Average no. of melons per plot					
Practice	Frequency	Quantity	23's	27's	36's	45's	Culls	Green fruit
Trickle to end of harvest	Weekly	1.20*	20.4	20.8	17.2	16.2	6.6	12.8
		0.97	6.8	15.0	16.2	19.0	6.8	14.4
		0.77	4.8	8.0	16.2	23.6	9.6	8.4
	Daily	1.20	12.6	19.0	20.8	19.8	10.8	11.0
		0.97	14.8	18.0	19.0	17.8	9.6	18.0
		0.77	3.4	7.0	14.4	24.2	13.0	4.4
Trickle to beginning of harvest	Weekly	0.98	16.4	19.6	14.6	16.0	11.2	10.0
		0.81	7.0	12.2	20.2	22.4	9.4	11.0
		0.65	3.2	6.4	17.6	25.6	13.8	6.0
	Daily	0.98	10.4	16.2	16.0	19.2	15.0	7.4
		0.81	11.0	14.2	23.8	24.6	12.6	7.0
		0.65	2.6	7.0	14.6	23.6	14.0	4.0
Furrow	Variable	1.15	16.2	16.2	17.5	18.3	9.8	9.0

*Ratio of season consumptive use of 18.2 inches measured on furrow irrigation plots.

Table 4. First week quality of spring cantaloupes (3 picking dates, mean of 60 fruit), 1978.

Irrigation Treatment			Percent[1/]	General[2/]	Netting[2/]	Outside[2/]	Flesh[2/]	Flesh[2/]	Cavity[2/]	Cavity[3/]	Cavity[3/]
Practice	Frequency	Quantity	sugar	appearance		color	color	firmness	dryness	length	width
										(cm)	(cm)
Trickle to end of harvest	Weekly	1.20*	12.4	6.0	6.4	6.6	6.3	6.7	5.5	8.5	5.9
		0.97	13.0	5.8	6.1	6.4	6.1	7.2	5.7	8.2	5.8
		0.77	13.0	5.7	6.0	6.3	5.9	6.8	5.2	7.9	5.6
	Daily	1.20	11.8	5.8	6.2	6.4	5.8	6.4	5.1	8.3	5.9
		0.97	12.7	5.7	6.2	6.4	6.0	6.8	5.4	8.5	5.9
		0.77	12.7	5.8	6.0	6.3	5.9	6.8	5.4	7.8	5.5
Trickle to beginning of harvest	Weekly	0.98	12.1	5.8	6.1	6.4	6.1	6.5	5.5	8.7	5.8
		0.81	13.0	5.8	6.1	6.3	5.8	6.6	5.6	8.3	5.8
		0.65	12.9	5.8	6.1	6.3	5.9	6.9	5.3	8.0	5.8
	Daily	0.98	11.8	5.8	6.2	6.5	6.0	6.7	5.5	8.2	5.8
		0.81	12.6	5.9	6.3	6.4	5.9	6.8	5.4	8.3	5.8
		0.65	12.9	6.1	6.2	6.5	5.8	6.9	5.5	7.9	5.7
Furrow	Variable	1.15	13.8	5.9	6.5	6.6	6.2	7.0	5.8	8.4	6.0

* Ratio of seasonal consumptive use of 18.2 inches measured on furrow irrigation plots.

1/ Measured by a handheld sugar refractometer.

2/ Visual evaluation, rated on a 1 through 9 scale, with 9 the most desirable.

3/ Measured by a handheld ruler.

Table 5. Second week quality of spring cantaloupes (2 picking dates, mean of 40 fruit), 1978.

Irrigation Treatment			Percent[1/]	General[2/]	Netting[2/]	Outside[2/]	Flesh[2/]	Flesh[2/]	Cavity[2/]	Cavity[3/]	Cavity[3/]
Practice	Frequency	Quantity	sugar	appearance		color	color	firmness	dryness	length	width
										(cm)	(cm)
Trickle to end of harvest	Weekly	1.20*	12.3	5.7	5.9	6.2	5.1	6.5	5.1	8.9	6.2
		0.97	12.5	5.0	5.3	6.4	4.7	6.2	5.1	8.4	6.0
		0.77	11.9	5.3	5.4	6.1	5.1	6.3	4.6	8.5	5.9
	Daily	1.20	11.6	5.0	5.4	6.1	4.8	5.9	4.8	8.7	6.1
		0.97	11.4	4.6	5.1	5.7	4.6	6.0	4.9	8.6	5.9
		0.77	11.7	5.4	5.4	6.3	4.8	6.2	4.9	8.2	5.8
Trickle to beginning of harvest	Weekly	0.98	11.8	5.1	5.7	6.3	4.9	6.6	5.2	8.5	6.0
		0.81	11.1	4.9	5.4	6.1	4.4	6.4	4.9	8.5	6.0
		0.65	12.7	5.2	5.6	6.5	4.8	6.4	4.9	8.3	5.8
	Daily	0.98	11.6	5.3	5.7	6.2	5.1	6.2	5.0	8.8	6.2
		0.81	11.0	4.1	5.4	6.2	4.3	6.3	5.2	8.5	6.1
		0.65	11.1	4.4	5.7	6.2	4.3	6.2	4.6	8.5	5.9
Furrow	Variable	1.15	12.0	5.3	5.7	6.2	5.5	6.7	5.1	8.6	6.1

* Ratio of seasonal consumptive use of 18.2 inches measured on furrow irrigation plots.

1/ Measured by a handheld sugar refractometer.

2/ Visual evaluation, rated on a 1 through 9 scale, with 9 the most desirable.

3/ Measured by a handheld ruler.

Table 6. Summary of fall cantaloupe yields (mean of 5 replications), 1978.

Irrigation Treatment			Marketable crates per acre	No. of fruit[1/] per plot 36 and larger	Total no. fruit[2/] per plot harvested	Percent[3/] culls
Practice	Frequency	Quantity				
Trickle to end of harvest	Weekly	1.05*	216.5[b]**	24.8[b]**	59.4[abcd]**	34.9[ab]**
		0.86	196.0[b]	24.0[b]	54.2[bcd]	31.2[ab]
		0.71	96.0[cd]	9.8[cde]	49.4[cd]	60.4[de]
	Daily	1.05	208.0[b]	25.2[b]	61.4[ab]	35.1[ab]
		0.86	128.0[c]	15.0[c]	55.4[abcd]	53.2[cd]
		0.71	62.6[d]	4.2[e]	47.6[d]	70.2[e]
Trickle to beginning of harvest	Weekly	1.00	271.3[a]	36.6[a]	60.4[abc]	26.4[a]
		0.81	213.4[b]	26.4[b]	62.6	37.4[ab]
		0.68	93.3[cd]	9.0[de]	47.8[d]	58.7[de]
	Daily	1.00	211.8[b]	27.4[b]	66.4[a]	43.5[bc]
		0.81	119.1[c]	13.2[cd]	57.4[abcd]	60.4[de]
		0.68	73.7[d]	5.6[e]	54.0[bcd]	68.8[de]
Furrow	Variable	1.18	258.0	32.7	63.2	29.0

*Ratio of seasonal consumptive use of 16.1 inches measured on furrow irrigation plots.

**Means followed by the same letter belong to same population at the 5% level of significance.

1/ Melons of size 23, 27, and 36 are included (Table 7).
2/ Melons of size 23, 27, 36, and 45 plus culls are included (Table 7).
3/ Number of culled fruit divided by the total number of fruit per plot harvested, expressed as a percentage.

Table 7. Grading of fall cantaloupes (mean of 5 replications), 1978.

Irrigation Treatment			Average no. of melons per plot					
Practice	Frequency	Quantity	23's	27's	36's	45's	Culls	Green fruit
Trickle to end of harvest	Weekly	1.05*	11.2	8.4	6.4	12.0	21.4	16.4
		0.86	6.2	7.8	10.0	13.0	17.2	6.8
		0.71	1.4	4.2	4.2	9.8	29.8	8.0
	Daily	1.05	6.6	9.0	9.6	13.8	22.4	23.0
		0.86	2.8	7.0	5.2	9.4	30.2	12.6
		0.71	0.8	1.8	1.6	9.6	33.8	2.2
Trickle to beginning of harvest	Weekly	1.00	13.6	11.8	11.2	9.8	16.0	9.8
		0.81	7.4	9.8	9.2	12.8	23.4	3.4
		0.68	0.8	4.0	4.2	10.6	28.2	1.4
	Daily	1.00	11.6	7.8	8.0	9.0	30.0	12.4
		0.81	4.2	5.0	4.0	9.2	35.0	5.8
		0.68	0.6	1.0	4.0	11.2	37.2	0.6
Furrow	Variable	1.18	13.0	10.5	9.2	12.2	18.3	13.3

*Ratio of seasonal consumptive use of 16.1 inches measured on furrow irrigation plots.

Table 8. First week quality of fall cantaloupes (2 picking dates, mean of 40 fruit), 1978.

Irrigation Treatment			Percent[1/]	General[2/]		Outside[2/]	Flesh[2/]	Flesh[2/]	Cavity[2/]	Cavity[3/]	Cavity[3/]
Practice	Frequency	Quantity	sugar	appearance	Netting[2/]	Color	Color	firmness	dryness	length	width
										(cm)	(cm)
Subsurface trickle	Weekly	1.05*	10.9	5.5	6.0	5.9	5.4	5.9	4.5	8.6	5.6
		0.86	11.5	5.6	6.1	5.9	5.4	5.8	4.7	7.9	5.3
		0.71	12.7	4.6	5.2	5.1	5.5	6.3	4.5	7.3	5.0
	Daily	1.05	10.4	4.6	5.5	5.1	4.8	6.0	4.3	8.4	5.5
		0.86	9.9	4.4	4.7	4.6	5.0	5.3	3.9	7.5	5.0
		0.71	12.2	4.7	5.0	4.9	5.3	5.7	4.5	7.4	5.2
Subsurface trickle early cut-off	Weekly	1.00	10.1	5.9	6.3	6.3	5.2	5.9	4.6	8.4	5.5
		0.81	11.3	5.3	5.9	5.8	5.2	6.1	4.6	8.2	5.4
		0.68	12.4	4.8	5.2	5.2	5.2	5.8	4.2	7.3	5.0
	Daily	1.00	10.5	5.2	5.6	5.7	5.3	5.7	4.6	8.6	5.7
		0.81	10.6	4.5	4.7	4.7	5.2	5.5	3.8	7.6	4.9
		0.68	10.9	4.3	4.6	4.6	4.6	5.3	3.8	7.3	5.0
Furrow	Variable	1.18	11.1	5.5	6.1	5.9	5.4	6.3	4.6	8.3	5.6

* Ratio of seasonal consumptive use of 16.1 inches measured on furrow irrigation plots.

1/ Measured by a handheld sugar refractometer.

2/ Visual evaluation, rated on a 1 through 9 scale, with 9 the most desirable.

3/ Measured by a handheld ruler.

Table 9. Second week quality of fall cantaloupes (1 picking date, mean of 20 fruit), 1978.

Irrigation Treatment			Percent[1/]	General[2/]	Netting[2/]	Outside[2/]	Flesh[2/]	Flesh[2/]	Cavity[2/]	Cavity[3/]	Cavity[3/]
Practice	Frequency	Quantity	sugar	appearance		Color	color	firmness	dryness	length	width
										(cm)	(cm)
Subsurface trickle	Weekly	1.05*	11.0	5.1	5.5	5.2	4.5	5.6	3.9	8.2	5.2
		0.86	11.3	5.5	5.7	5.9	6.4	6.2	4.1	8.2	5.3
		0.71	12.4	4.8	5.1	4.8	5.8	5.7	3.7	7.2	4.8
	Daily	1.05	10.3	4.7	5.5	5.2	5.4	5.3	3.8	8.3	5.2
		0.86	11.4	5.0	5.3	5.1	6.1	5.5	3.5	7.8	4.8
		0.71	12.1	5.0	5.1	5.1	5.6	5.1	3.8	7.4	5.0
Subsurface trickle early cut-off	Weekly	1.00	10.2	5.9	6.3	6.2	5.5	5.4	4.4	8.7	5.8
		0.81	11.4	6.3	6.4	6.3	6.7	6.0	4.1	8.2	5.5
		0.68	13.0	4.7	5.0	5.0	5.8	5.7	3.9	7.5	5.0
	Daily	1.00	10.0	4.7	5.1	5.2	5.1	5.2	3.7	8.5	5.5
		0.81	11.5	4.9	5.1	5.0	6.3	5.6	4.0	7.7	5.1
		0.68	11.1	4.9	5.2	5.2	5.3	5.2	3.3	7.3	4.8
Furrow	Variable	1.18	11.8	5.8	6.1	6.0	6.0	6.1	4.7	8.4	5.7

* Ratio of seasonal consumptive use of 16.1 inches measured on furrow irrigation plots.

1/ Measured by a handheld sugar refractometer.

2/ Visual evaluation, rated on a 1 through 9 scale, with 9 the most desirable.

3/ Measured by a handheld ruler.

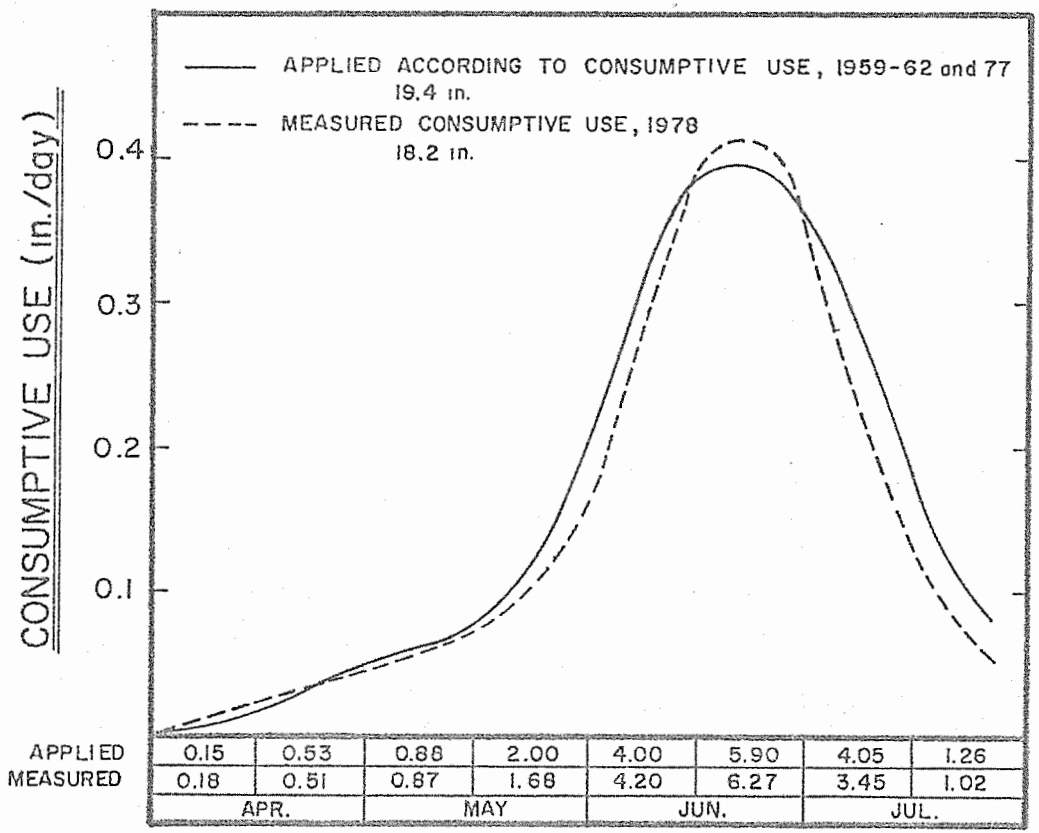


Figure 1. Applied and measured consumptive-use curves for spring cantaloupes, 1978.

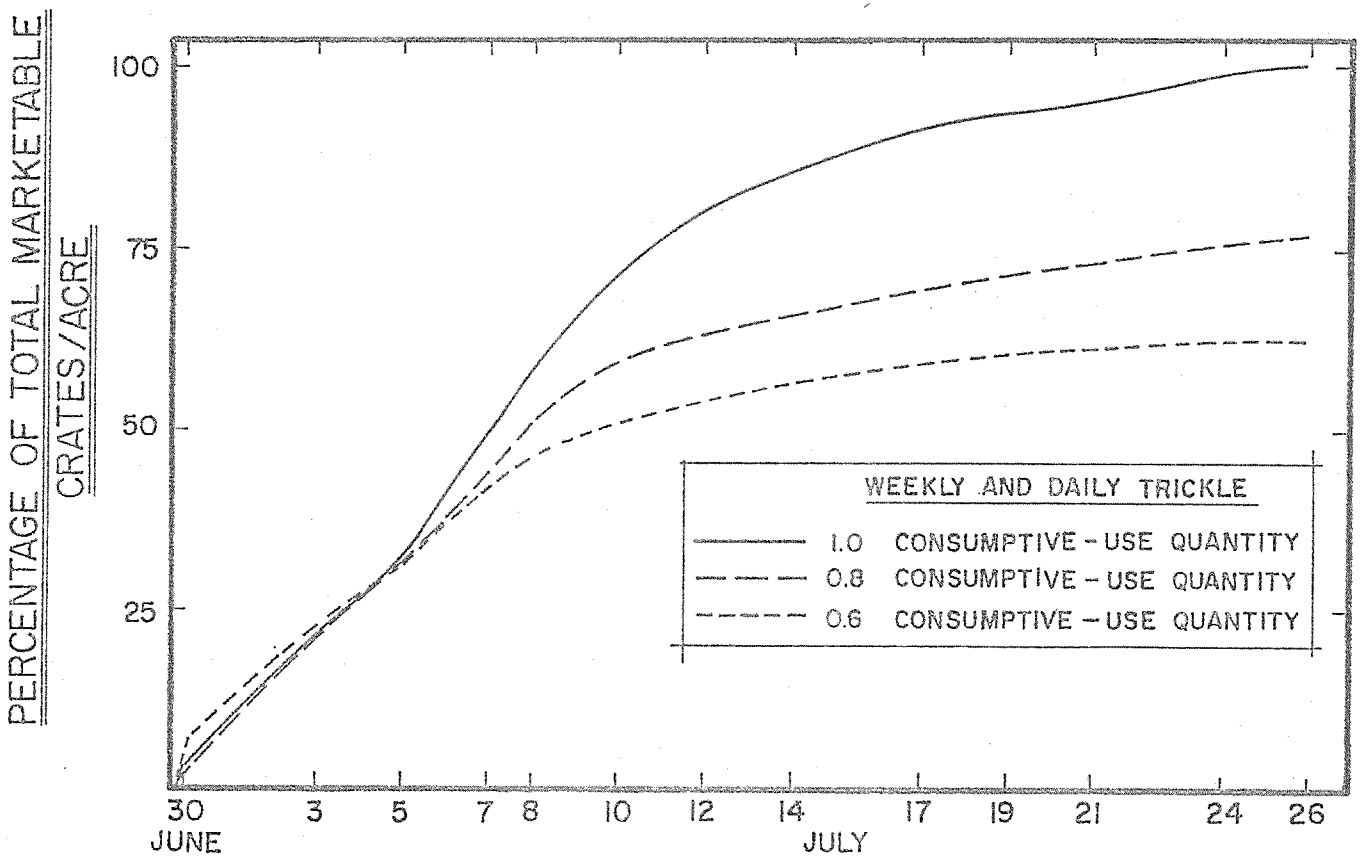


Figure 2. An accumulated percentage of total marketable crates per acre by harvest date for spring cantaloupes, 1978.

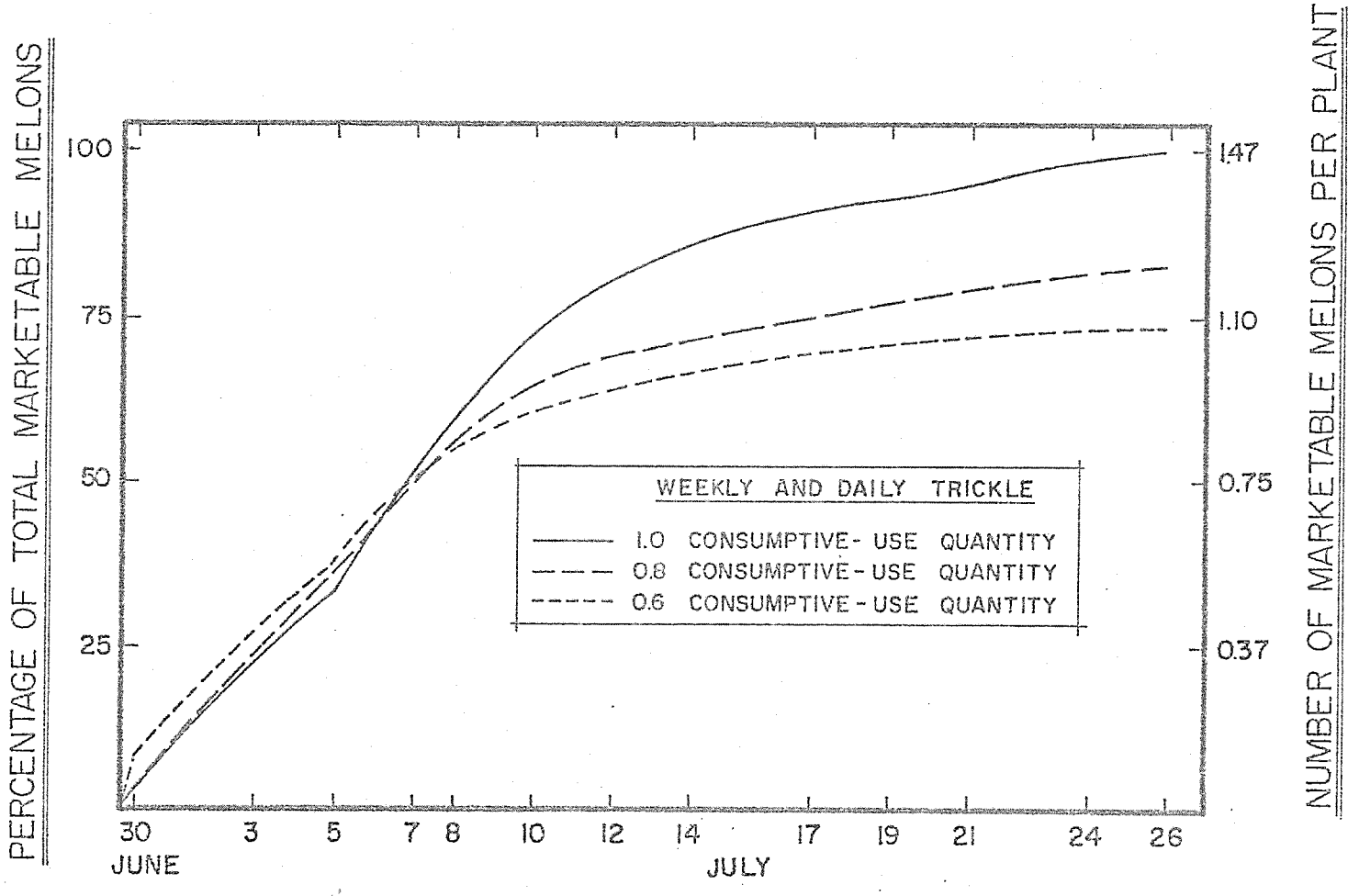


Figure 3. An accumulated percentage of total marketable melons by harvest date for spring cantaloupes, 1978.

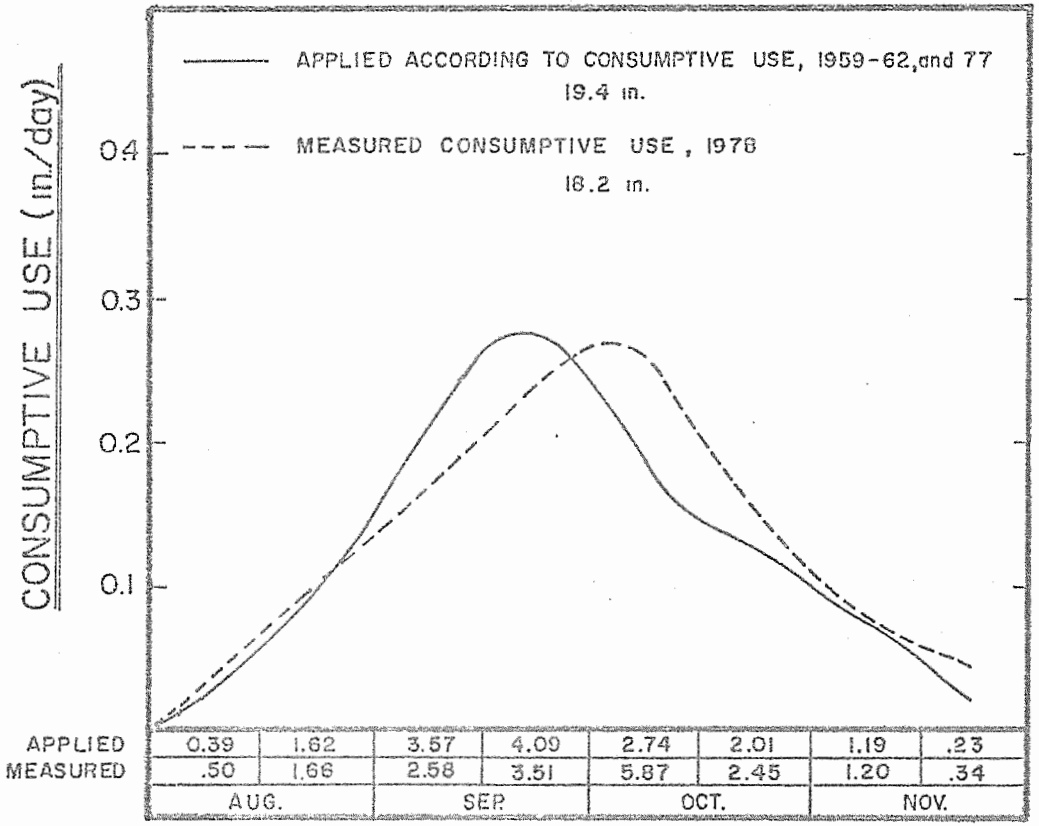


Figure 4. Applied and measured consumptive-use curves for fall cantaloupes, 1978.

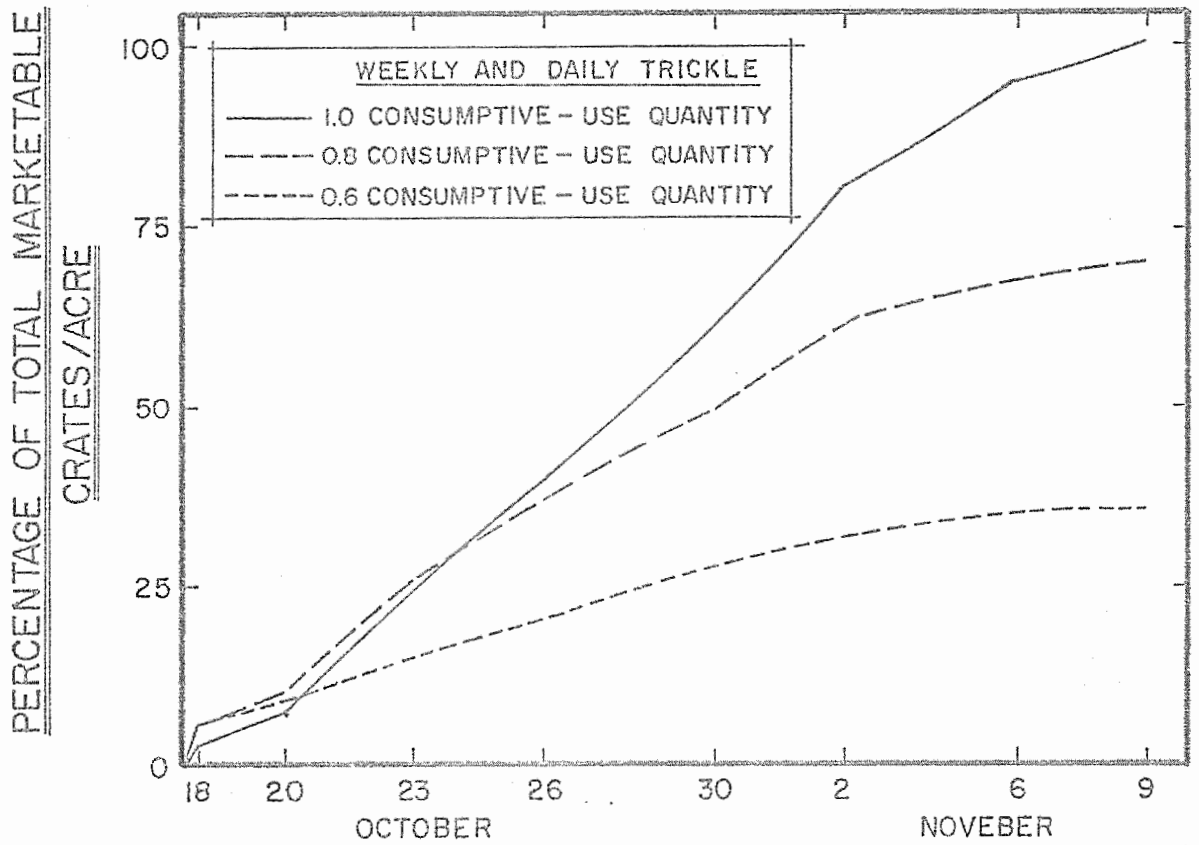


Figure 5. An accumulated percentage of total marketable crates per acre by harvest date for fall cantaloupes, 1978.

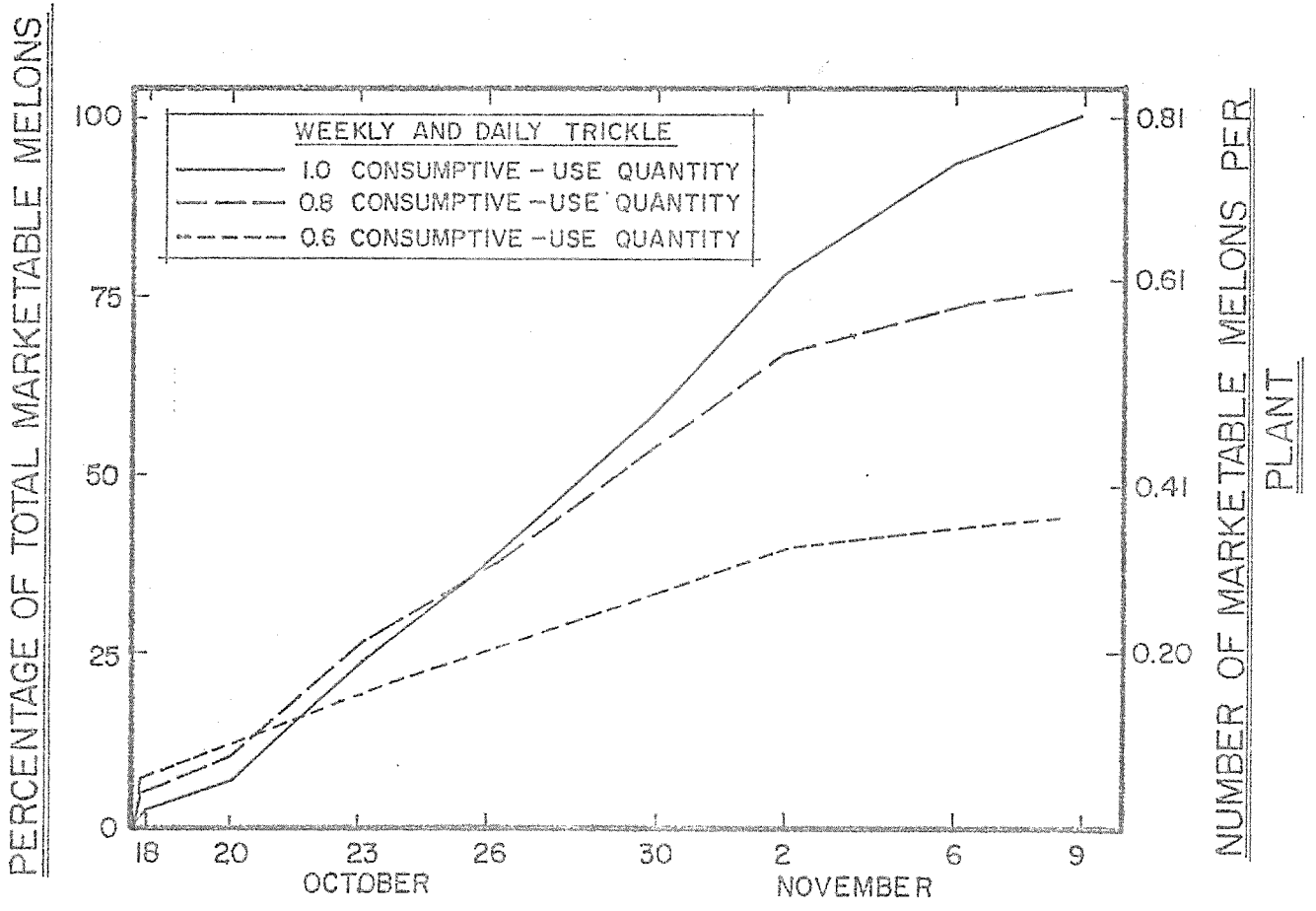


Figure 6. An accumulative percentage of total marketable melons and number of melons per plant by harvest date for fall cantaloupes, 1978.

TITLE: RESEARCH, DEVELOPMENT, AND DEMONSTRATION OF AUTOMATED SURFACE WATER DISTRIBUTION SYSTEMS FOR GRAVITY IRRIGATION

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 74-2

INTRODUCTION:

An automated irrigation system reduces farm labor requirements and as an irrigation tool, assures more precise control of the quantity of water applied. Better control of water results in water saving and generally crop yield improvement. Improving the irrigation efficiency will reduce the water return flow associated with the water quality degradation to a river system such as the Colorado River.

OBJECTIVES:

This study is a part of an effort to improve the irrigation efficiency in the Wellton-Mohawk Irrigation and Drainage District and resultant low water quality return flow to the Colorado River with objectives

1. To demonstrate (on-farm) the use of presently-available schemes for automating surface water distribution systems in the Wellton-Mohawk area of Arizona.

2. To design, develop, and demonstrate improved automated systems.

Two fields were automated in 1975, to demonstrate first a lift-gate operated surface distribution system, and then a concrete port outlet system in combination with lift-gates. Each system is pneumatically actuated by a clock-controller at a central location which signals irrigation field changes according to preset times. For further introduction, see 1975 Annual Report.

At the request of the Soil Conservation Service, we designed and installed the first cost-shared automated irrigation system as part of the on-farm irrigation improvement program administered by the Soil Conservation Service in the Wellton-Mohawk Irrigation and Drainage District. The system is on the Ron McDonnell-Bob McElhaney farm near Wellton, Arizona. Twenty-five lift-gates were automated

which service 23 fields averaging about 2.6 acres each. The system was installed in May 1977, and has been used to irrigate through two irrigation seasons.

RESULTS AND DISCUSSION:

Woodhouse Automation--Lift-Gates

The system was used for nearly all irrigations during 1978, but three times gate actuation problems were reported. In all cases the problem was traced to improper functioning of solenoid-operated, 3-way normally open valves associated with safety overflow and excess water disposal functions. The problem has been reported to the manufacturer. Generally, some foreign materials have been found in the valves but the source of the material is unknown. The valves will be replaced during 1979.

Upon burning bermuda grass along the canal, plastic tubing housed inside a plastic meter box was melted and had to be replaced. The plastic tubing should be insulated.

1978 completed nearly four years' operation of this automated equipment and most of the components--many never used in this environment previously--have functioned extremely well. The air cylinders still bypass hardly any air and the pneumatically-operated 4-way valves attached to the gates, continue to function satisfactorily. The system will continue to be used during 1979.

Naquin Automation--Ports and Lift-Gates

The automated port system on the Naquin farm was used about 15 times during 1978. All basins were in alfalfa. Changes or additions made to the system during 1978 included addition of quick exhaust valves near the ports of basins 1 through 4, isolation of the overflow signals, and redesign of the port closures to all basins except basin 3.

In the original design of the port system, air was vented at the control center, a distance of as much as 1900 feet, for ports to basins 1 and 2. Port closure (pressurization) under this condition was much quicker than port opening (depressurization/vent). The delay

between closure and opening caused an undesirable overflow actuation when making a normal switch from basins 1 to 2 or 3 to 4. In an effort to delay port closure, an air-throttling valve was installed in the air supply going to the upper four basins. Although this was an improvement, it did not eliminate the problem. I then installed quick exhaust valves in each air supply tube near each set of six bellows for basins 1 through 4. The valves were located in water meter boxes along the canal. Quick exhaust valves function as shuttle valves when air is supplied to the inlet, but exhaust to the atmosphere when the inlet pressure drops slightly. Hence, when the exhaust valve senses a decrease in pressure (basin switch signaled at control center) the air in the bellows is immediately exhausted at the quick exhaust valve rather than at the control center. This change proved to be satisfactory.

At least one overflow sensing unit is located on each canal reach upstream from a check gate or the end of a canal. The overflow turnouts (ports or gates) that are used with a particular overflow sensor should be those common to that reach of canal. In the original design of the Naquin system, however, overflow sensed by any one of three overflow sensors could operate all gates or ports as overflow turnouts, if so designated by the irrigator. This proved to be unsatisfactory when switching from lower-lying basins to upper basins since time delays were significant and port opening was slow. The problem was alleviated by isolating the overflow sensing devices so that:

Overflow (OF)	Basin ports or gates actuated
OF-1, Upstream from check gate (CG-1) adjacent to basins 1 and 2	Basins 1 and 2, Check gate 1
OF-2, Upstream from CG-2 adjacent to basins 3 and 4	Basins 3 and 4, CG-2
OF-3, Upstream from CG-3 adjacent to basins 5 and 6	Basins 5, 6, 7, or 8, and CG-3

Debris collecting on the port closures continued to be a problem during 1978. One closure was modified in 1976 by eliminating one of

the support legs, turning the structure 45°, and hanging the closure plate from the upper leg. Very little debris collected on this modified closure during 1977 and 1978. New structures for all ports except those leading to basin 3 were designed and built during the fall of 1978, and are to be installed in early 1979. The design was essentially the same as the one closure modified in 1976, except the support legs were farther away from the port ring than the originals and the plates were larger. Their function will be evaluated and compared to the originals still being used for basin 3.

Brass couplings used for connecting polyethylene tubing underground were examined when the quick exhaust valves were installed and were in excellent conditions.

The Naquin system will be used and evaluation continued during 1979.

McDonnell-McElhaney Automation

The system on the McDonnell-McElhaney farm has been used to irrigate through two irrigation seasons with very little problem. After the first two irrigations in 1977, the system has been used solely by the farmers. A few items have been evaluated or modified during 1978.

The particular gates to be opened when an overflow is sensed are selected by the irrigator by turning "on" a toggle-operated pneumatic valve attached to the 4-way valve at the gate (Valve 3 in Figure A). We have found that Valve 2 remains in a partially shifted position when air signals are received at both parts (N/O and N/C)--signal from both the timer and overflow to open the gate. If Valve 2 were replaced with a shuttle valve (configuration shown in Figure 1B) the problem would likely be eliminated. Such a replacement will be made during 1979.

Operation of the excess water disposal function is dependent upon a solenoid-operated air valve. The valve, the same as used on the Woodhouse system, occasionally leaked and was replaced by another valve from a different manufacturer--the same valve used on Naquin system for 2 years without problems.

Material that accumulated on the rod surface of the air cylinders has been removed 3 or 4 times by brushing over the 2-year period. Normally the rods would be wiped clean, but infrequent operation and rod exposure between irrigations had lead to the accumulation. It is easily removed but needs to be prevented if possible. Canvas sleeves are to be tried as a protective shield to the rods.

The time required for an air piloted valve to operate depends on tubing size and length, the operating pressure, and pilot activation pressure. Of prime importance, when automatically switching gates during an operation, is that a gate opens at the same time or before another gate closes. In last years' Annual Report we reported a laboratory-developed relation between distance to gate (valve) and time of actuation. In Figure 2 we show the actual situation for the McDonnell-McElhaney system. The difference in opening time to closure time for gates located at about the same distance from the control center is as much as 1 minute, 35 seconds at about 2200 ft. (last gate).

With the exception of the three normally open gates used for emergency water turnout in case of air loss to the system, all gates are closed between irrigations. In some instances this does not allow the canal to drain between irrigations and may cause rusting of the gates. A short helical spring was designed that could be loaded into gate cylinders to maintain a normally open gate (open only 1/2 to 3/4-inch) for drainage purposes. The spring characteristics were:

> Spring force at 0.75-inch displacement is about 600 pounds; freelength 2.50 inch; coils, 4-1/2; wire diameter, 0.225 inch; inside diameter, 1-1/32 inch; material 17-7 stainless steel.

The automated system was featured at a University of Arizona Extension Service-sponsored field day on 26 January 1978. The field day was attended by more than 70 growers and agribusiness leaders. In addition, an article entitled "Flood Irrigation Without Fuss" was published in The Furrow magazine, April 1978, Vol. 83, Issue 4, featuring the automated irrigation system on the McDonnell-McElhaney

farm. The farmers have demonstrated the system to many individuals and groups other than organized demonstrations.

Hoffman Automation

I designed two more automated systems during 1978 that are part of the SCS irrigation improvement program in the Wellton-Mohawk Irrigation and Drainage District. The fields to be automated, both farmed by Joe Hoffman, are located about 20 miles apart. The first field (110 acres) is divided into 8 basins, 4 on each side of the nearly 3000-ft concrete lined canal. The second field features 12 basins on nearly 80 acres. Length of the canal in the second field is just over 2000 ft. Both systems use lift-gates (jack-gates) as single inlets to the individual basins.

The two primary differences between these systems and any done previously are (1) the electrical wire and air tubing is directly embedded in the concrete canal lining (for gopher protection) during the slipforming operation, and (2) a portable control center is used that is independent of 110 VAC power.

Embedding of the wire and tubing (5/16-inch O.D. polyethylene) was possible since the canal lining contractor operating in the Wellton-Mohawk District, Mr. Fred Crabtree, was willing to have his slipform modified to allow for proper wire and tubing placement. Modification included attachment of a rack to the slipform for carrying spools of wire and tubing, and cutting two holes in the chute to provide entry of guides used for placement of the wire and tubing in the desired position. Wires and tubes were located on both sides of the liner along the outside lip of the canal. This location provided access to the tubes and wires where gates were to be located. The first canal was lined in December 1978, and required about 6 hours to complete. The wire and tubing placement caused little delay in the canal lining operation. The embedding operation was successful, but the action of the concrete on the tubing and wire over a period of time is unknown. The second canal will be lined in February 1979.

Portable control centers (trailers) have been previously used at other locations, but 110 VAC power was always available. Electrical power to these fields would be quite costly, hence we decided to try a control center independent of AC power. Gate actuation requires pressurized air at about 50 psi. Bottled air or nitrogen supplied at 2200 psi (240 ft^3 at atmospheric pressure) will be tried. Several air bottles will be carried on the trailer. Preliminary calculations and tests in the laboratory indicate that three irrigations may be attainable with one bottle providing the system is relatively air tight. To reduce the air required, 24 VDC solenoid-operated (rather than air-piloted) 4-way valves will be used to divert air for opening/closing of the gates, since battery power is easier to maintain than an air supply. The controller to be used will be provided by Aquamatic. Timing is digital (minutes or hours-tenths hour). The controller is normally powered by 110 VAC but will be modified for 12 VDC operation.

Other system features include:

(1) Air cylinders

(a) Maximum gate opening, 18 inches
(b) Cylinder bore, 3-1/2 inches (not spring loaded)
(c) Cylinders mounted so that rods retracted between irrigations for protection against weathering

(2) Structural tubing was used to transfer the wire and tubing across erosion control structures. They were embedded in the concrete and the tubing and wire were threaded through when the gates were installed. Lids, about 18 inches long, were fabricated on the tubing, to allow access to the 4-way valve and 3 toggle switches housed inside the tubing.

(3) Selector switches (three) will be located at each gate to allow irrigator selection of overflow gates, and irrigator actuation of the gate without returning to the control center--open gate if in closed position or close gate if in open position.

Installation of the systems will be completed during the spring of 1979 and both will be used to irrigate cotton the first year. The

portability of the control center will be severely tested since the distance separating the fields is about 20 miles.

SUMMARY AND CONCLUSIONS:

Two fields were automated in 1975 in the Wellton-Mohawk Irrigation and Drainage District to demonstrate (on-farm) the use of presently available automated schemes for controlling irrigation water to level basins and to design, develop, and demonstrate improved systems. One 65-acre field on the Bob Woodhouse farm uses lift-gates to control the water, while on a 70-acre field on the Jim Naquin farm, concrete port outlets in combination with lift-gates are used. Each system is pneumatically actuated by a clock/controller at a central location which signals irrigation field changes according to preset times. The systems were each used about 15 times during 1978 for a total, since installed, of about 100 irrigation events. This type of experience and use of the systems has been invaluable in development ofimproved systems. Most of the irrigations have been completed by the farmer/irrigator.

Gate actuation problems occurred during three irrigations in 1978 on the Woodhouse system. In all cases the problem was traced to improper functioning of solenoid-operated, 3-way normally open valves associated with safety overflow and excess water disposal functions. This, however, was the only component problem encountered and will be corrected during 1979.

Changes or additions to the Naquin system during 1978 included addition of quick exhaust valves near basins 1 through 4 to shorten the time of port opening; isolation of overflow signals so that an overflow sensor operated gates or ports common to that particular overflow; and port closures were redesigned and built in an effort to minimize debris collection. The closures will be tested during 1979. The original closures to basin 3 will be used for comparison purposes.

Two technical papers describing the Woodhouse and Naquin systems were published in the Transactions of the American Society of

Agricultural Engineers. The papers are entitled "Automation of On-Farm Irrigation Turnouts Utilizing Jack-Gates" and "Automation of Open Ditch Irrigation Conveyance Systems Utilizing Tile Outlets."

In May 1977, the first cost-shared automated irrigation system was installed as part of the Soil Conservation Service's on-farm irrigation improvement program in the Wellton-Mohawk Irrigation and Drainage District. The system, featuring pneumatically signalled and actuated lift-gates, has been used through two irrigation seasons solely by McDonnell and McElhaney, the owner-operators. The valve arrangement used to select which gates should actuate when an overflow is sensed fails to function properly when air signals are received from both the timer and overflow. The problem will be alleviated during 1979 with the use of a different valve. Canvas sleeves are to be placed over the exposed cylinder rods in an effort to eliminate material accumulation.

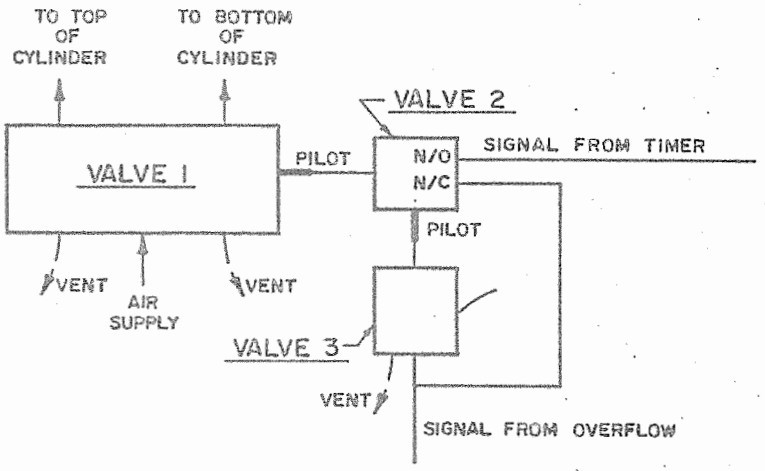
The automated system was featured at a University of Arizona Extension Service-sponsored field day on 26 January 1978. The field day was attended by more than 70 growers and agribusiness leaders. In addition, an article entitled "Flood Irrigation Without Fuss" was published in The Furrow magazine, April 1978, Vol. 83, Issue 4, and featured the automated irrigation system on the McDonnell-McElhaney farm. The farmers have demonstrated the system to many individuals and groups other than organized demonstrations.

Two more automated systems were designed during 1978 that are part of the SCS irrigation improvement program in the Wellton-Mohawk Irrigation and Drainage District. The fields to be automated, both farmed by Joe Hoffman, are located about 20 miles apart. The first field (110 acres) is divided into 8 basins, 4 on each side of the nearly 3000-ft concrete-lined canal. The second field features 12 basins on nearly 80 acres. Length of the canal in the second field is just over 2000 ft. Both systems use lift-gates (jack-gates) as single inlets to the individual basins.

The two primary differences between these systems and any done previously were (1) the electrical wire and air tubing is directly embedded in the concrete canal lining (for gopher protection) during the slipforming operation, and (2) a portable control center is used that is independent of 110 VAC power. Controller and solenoid operation will be 12 and 24 VDC powered, respectively. Air used for gate actuation will be supplied from air bottles at 2200 psi (240 ft^3 at atmospheric pressure). Embedding of the air lines and electrical wires was successfully completed for the 3000-ft canal in December 1978. The placement of the wire and tubing caused very little delay in the lining operation. The second canal will be completed in February 1979.

PERSONNEL: Leonard J. Erie and Allen R. Dedrick

(A)



(B)

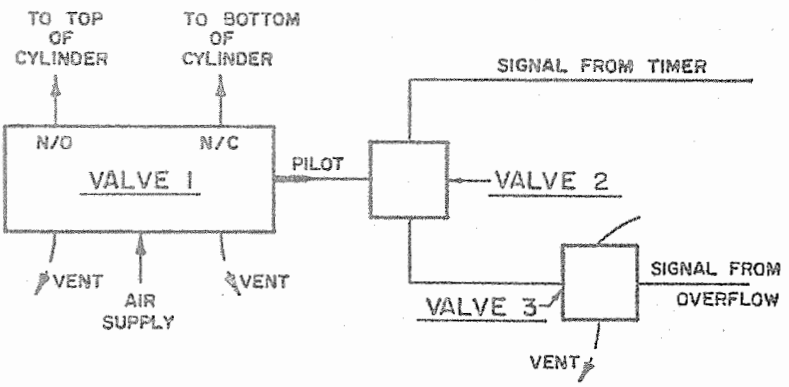


Figure 1.--(A) Original valve arrangement to allow for irrigator selection of overflow gates for McDonnell-McElhaney automated system. Valve 1: 4-way, pneumatically piloted, spring return valve mounted on gate frame. Valve 2: 3-way, pneumatically piloted diverter valve. Valve 3: toggle operated pneumatic valve. (B) Proposed modification replacing valve 2 with a shuttle valve.

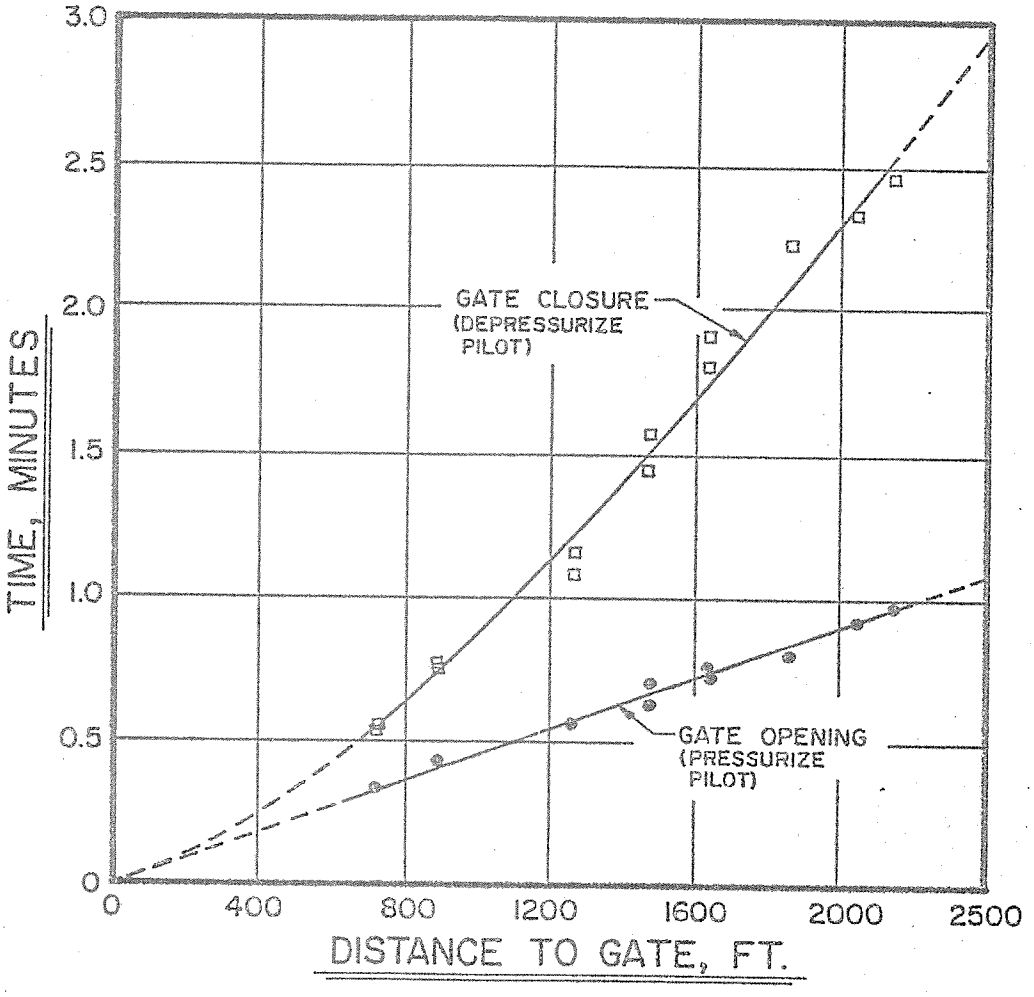


Figure 2.--Time required for the pilot of the 4-way pneumatically actuated valve, mounted on the field gates of the McDonnell-McElhaney automated system, to operate when pressurized (gate opened) from atmospheric pressure and depressurized (gate closed) from 50 psi operating pressure related to signal length or distance to gate. The signal line tubes were 1/8-inch ID polyethylene tubing.

TITLE: TIME RATE MOVEMENT OF WATER FOR DEAD LEVEL IRRIGATION

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 74-3

INTRODUCTION:

More efficient irrigation within the Wellton-Mohawk Irrigation and Drainage District potentially can reduce the drainage requirement and associated quantity of salt returned to the lower Colorado River system near Yuma, Arizona. The irrigation application efficiency in many cases can be improved by changing the farm irrigation system. A method referred to as level-basin irrigation can be highly efficient and represents one such change.

For further introduction, see 1975 Annual Report.

OBJECTIVES:

(1) To determine the effects on time-rate-of-advance for level-basin irrigation systems that are caused by:
   (a) Field configuration
   (b) Stream size or application rate
   (c) Number and location of outlet structures

(2) To publish a practical publication explaining design principles and water management criteria, including consideration of cultural changes for implementing level-basin irrigation.

PROCEDURE:

Several time-rate-of-advance studies associated with the first objective were planned and have been completed. Design principles, water management criteria, land preparation, cultural changes, and other aspects for using level basins have been or are to be published.

RESULTS AND DISCUSSION:

A manuscript entitled "Level-basin irrigation: A method for conserving water and labor" was prepared and submitted to the USDA Information Division for publication as a Farmers Bulletin. Also a paper entitled "On-farm level-basin irrigation - Save water and energy" was published in the Civil Engineering magazine. In it we described the role of technological inputs like laser controlled land leveling, irrigation turnouts, mechanization, and improved water measurement techniques when used in conjunction with level basins.

The concept of level-basin irrigation has been introduced to many potential users during 1978. This has been done by participating in workshops; farmer meetings; field days; tours and discussions with farmers from Utah, Nevada, and California; private consultants; and through presentations to university classes.

SUMMARY:

The utility of level basins as a low energy, high efficiency and labor saving irrigation technique has continued to be emphasized to potential users in Arizona, California, Colorado, Nevada, New Mexico, and Utah. Some usage is expected to start in most of these states during 1979.

PERSONNEL: L. J. Erie and A. R. Dedrick

TITLE: CLOGGING POTENTIAL OF COLORADO RIVER IN TRICKLE IRRIGATION SYSTEMS AND DEVELOPMENT OF METHODS FOR PREVENTING PLUGGING

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE: USWCL 75-2

INTRODUCTION:

Part of the original outline was modified to include work being conducted under Ariz.-WCL 71-11, "Chemical treatment of irrigation water for the prevention of clogging and the removal of flow obstructions in trickle irrigation systems." A formal Annual Report covering the activities at Tacna, Arizona for 1978, has been given to the Soil Conservation Service and Bureau of Reclamation, the original funding agency. We were able to extend the study period for a fourth year so additional information on clogging and operation and maintenance practices could be obtained. The results will be summarized in a later section.

Another aspect of great importance related to clogging is that dealing with uniformity of water application. Portions of this were discussed in the 1977 Annual Report (Ariz.-WCL 71-11). Besides uniformity or non-uniformity of water distribution, fertilizer, herbicide and other materials added with the trickle system must be considered when application uniformity is considered.

PROCEDURE:

A simulation model was developed for estimating coefficient of variation when a certain fraction of the emitters in the trickle system become clogged. In this approach, a statistical emitter population is first established for an orchard area with a specified number of trees in the unit area. The system can include from one to 10 or more emitters per plant. In the computational procedure, enough emitters are selected randomly from a theoretical statistical population with a defined emitter flow rate and standard deviation that will make up the trickle system. This procedure would be like picking emitters from a group of emitters supplied by the manufacturers to the farm operator for installation into the irrigation system. The average

flow rate and standard deviation (or coefficient of variation) would be the values provided by the manufacturer.

Once the simulated emitter population is established with the normal range of flow rates and frequencies, emitters are randomly selected for clogging using the random number generator of the computer. Furthermore, the routine is programmed so that the same emitter is not clogged again when multiple clogging events are simulated. Resultant system flow rates and coefficient of variation and other statistics are calculated after the original emitter population is modified through clogging.

RESULTS AND DISCUSSION:

The computed coefficients of variation for the clogging with different numbers of emitters per plant are illustrated in Figure 1. Obviously, clogging effects on uniformity are greatest with the system having only one emitter per plant. Two emitters per plant improve upon the coefficient of variation for the same percent of clogging. Four to six emitters per plant appear to be the better combination to use. If yield function versus uniformity of application is available, econometric computation could be made to determine the optimum number of emitters per plant to use.

By applying the interrelation developed last year between coefficient of variation, coefficient of uniformity and number of emitters per plant, the effect of clogging can be incorporated into the system. Results of Table 1 reinforce numerically the intuition-derived concepts that more emitters per plant would give better water application distribution and also the system can tolerate more degree of emitter clogging. Precaution must be taken with the use of the number, however, since even with 80 to 90 percent uniformity coefficient, only 80 to 90 percent of the plants will be adequately irrigated. To achieve 100 percent adequacy, more irrigation water is needed, but some plants would be over-irrigated, consequently causing a decrease in irrigation efficiency.

SUMMARY:

Long-term observations on trickle emitters are necessary to evaluate emitter performance and reliability. Experiments have shown

that emitters exhibiting good potential in the first and even second year of operation could develop flow problems. In the water treatment, removal of suspended material is important for proper operation of most types of emitters. Acid treatment with filtration for the Colorado River water was as effective as the combination hypochlorite-acid treatment for maintaining emitter operation. Apparently, microbial activity is not as great a problem with this water for the site as other locations.

A simulation model based on statistics that accounts for the clogging of emitters and its effect on application uniformity was developed. The effect of emitter clogging with various combinations of emitters per plant is clearly demonatrated even with 5 to 10 percent of the emitters being clogged. Two or more emitters per plant are necessary to maintain adequate water application uniformity in such situations.

PUBLICATIONS:

1. Nakayama, F. S., Gilbert, R. G., and Bucks, D. A. 1978. Water treatment in trickle irrigation systems. J. Irrig. and Drain. Div., Amer. Soc. Civil Engin. 104(IR1):23-24.

2. Nakayama, F. S., Bucks, D. A., and Clemmens, A. J. 1978. Assessing trickle emitter application uniformity. Trans. Amer. Soc. Agric. Eng. (In press).

3. Bucks, D. A., Nakayama, F. S., and Gilbert, R. G. 1978. Trickle irrigation water quality and preventive maintenance. Agric. Water Manage. (In press).

4. Gilbert, R. G., Nakayama, F. S., and Bucks, D. A. 1978. Trickle irrigation: Prevention of clogging. Trans. Amer. Soc. Agric. Eng. (In press).

PERSONNEL: F. S. Nakayama, B. A. Rasnick, D. A. Bucks, O. F. French, R. G. Gilbert

Table 1. Interrelationship between number of emitters per plant, percent emitters clogged and uniformity coefficient.

No. of emitters per plant	Uniformity Coefficient (%) Percent clogged emitters						
	0	1	2	5	10	15	20
1	92	90	87	80	73	65	60
2	96	95	93	90	87	84	76
4	98	97	96	95	93	91	89
8	99	98	97	96	95	94	93

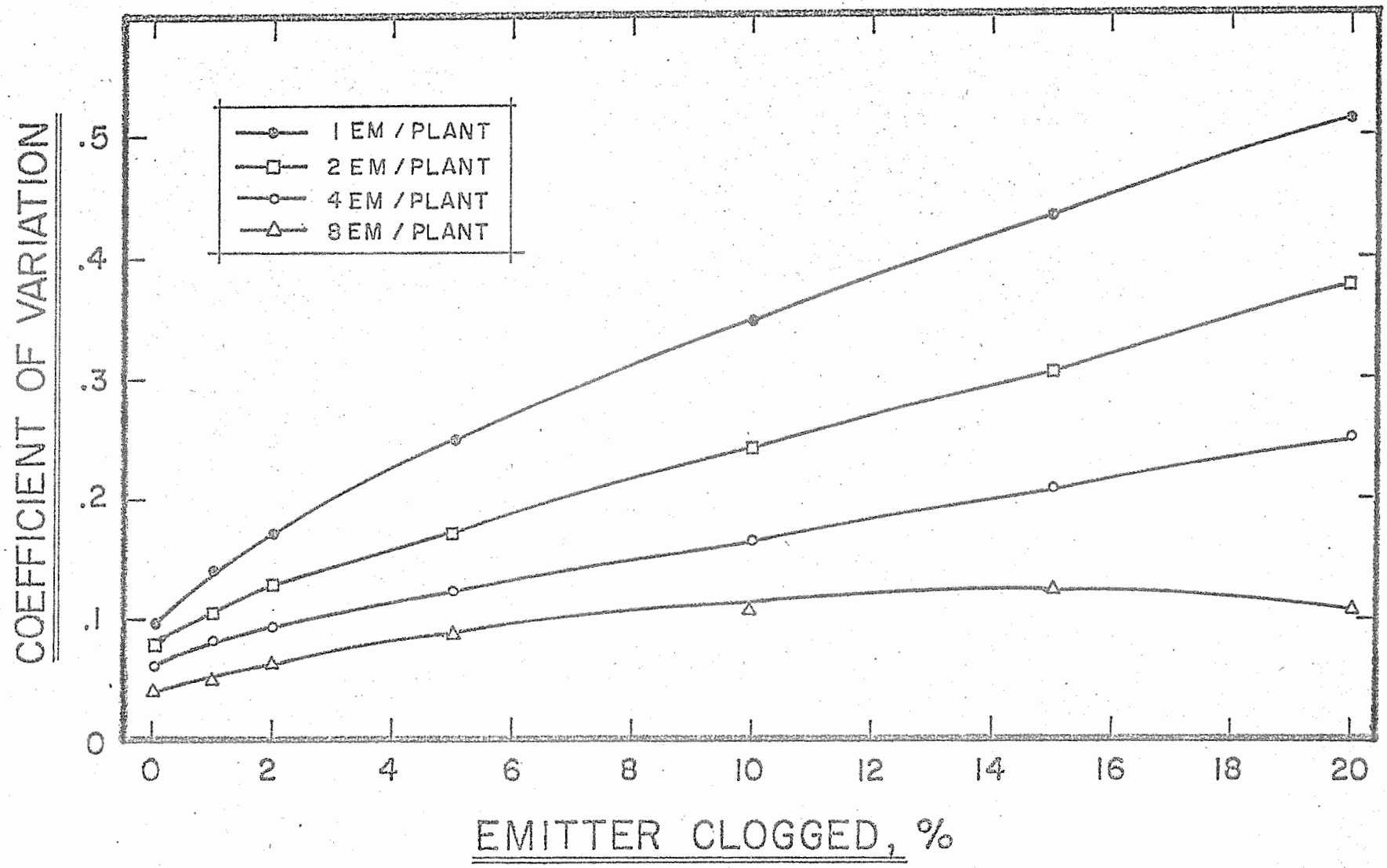


Figure 1. Clogging effect on the coefficient of variation for emitter flow rate with different numbers of emitters per plant.

TITLE: FIELD EXPERIMENTS FOR SURFACE IRRIGATION MODEL

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 78-10

INTRODUCTION:

An experiment was initiated to provide additional verification of the mathematical models that have been developed for border irrigation. Additional objectives are to test methods of estimating the infiltration rates of a soil from surface water hydraulics and to develop practical guides for estimating surface roughness in irrigation borders. During 1978, three fields (C-1, B-1, B-2) with acreages 3.94, 3.74 and 9.32 were laser leveled to slopes of 0.000, 0.001 and 0.0005, respectively. Special border dikes were constructed by pulling up two extra high border dikes next to each other. A blade was used to knock soil back into the dead furrow on the field side of the dikes. The area between the two dikes was convenient for walking up and down the field while irrigating. The border strips were all about 617 ft long and the widths were 110, 40, and 80 on the smaller fields and 120, 40, 80, 120, 40, and 80 on the larger field. All borders were blocked to prevent runoff.

EXPERIMENTS:

The alfalfa seed was flown on to minimize vehicle traffic, then tilled into the soil. The first irrigation was made on September 21, 1978 just after planting. Advance and recession were observed on all 12 borders. Ring infiltration data was taken on the two outside borders of field C-1 (level) at 100 ft intervals, starting at station 0 + 50 and ending at station 5 + 50. Bouwer's method of determining infiltration rates was used to estimate the infiltration rates for this irrigation. When all 12 borders were used, the results looked good and are plotted in Figure 1. However, one standard deviation in average depth applied represents about 1 inch at 3 1/2 hours, which was almost 30%. Also, when using this method on only a few borders, the results were rather poor, indicating that the infiltration was different in different borders. Difficulty in determining recession times also probably affected the analysis. The ring data

was plotted on log-log paper, both the infiltration rate and the cumulative infiltration. A volume balance showed that the data under-predicted the infiltrated volume by about 30%. Both sets of data were adjusted to reach a volume balance and are plotted in Figure 1. A comparison with Bouwer's method would indicate that the infiltration rate data was probably better than the cumulative infiltration data. Since the soil is a clay loam (Avondale), this is reasonable. However, on more coarse-textured soil, the reverse is usually true.

The zero-inertia border irrigation model was used to estimate the advance and recession on these borders based on the infiltration data taken. In general, the model predicted advance too slowly, most likely due to the value chosen for the Manning roughness coefficient. The laser leveled fields with almost no tillage were apparently smoother than indicated by the Soil Conservation Service, who recommend n = 0.04 for bare soil. A second irrigation was run on October 11, 1978 with similar results. Additional rings were set out to determine the effects of driving the cylinders on the infiltration. No correlation existed.

To obtain more realistic, usable data, some water depth measurements will be necessary to obtain water surface profiles. This will improve the estimates of both infiltration rates and surface roughness.

Small lift gates were installed on Field C-1 and small erosion control structures were built. Erosion was caused by floor jets which were not blocked off by the temporary sills. These gates will eventually be automated to facilitate fast set changes. Use of the gates helps to maintain a uniform, stable discharge down the border which is necessary for this study.

SUMMARY:

A field experiment has been initiated in an attempt to obtain better data over a wider range of field conditions to investigate the usefulness of hydraulic modeling of the irrigation process and to verify existing models. Preliminary investigations have shown that some water depth measurements are necessary in order to obtain

accurate estimates of infiltration and flow resistance.

PERSONNEL: Albert J. Clemmens, Allen R. Dedrick, John A. Replogle

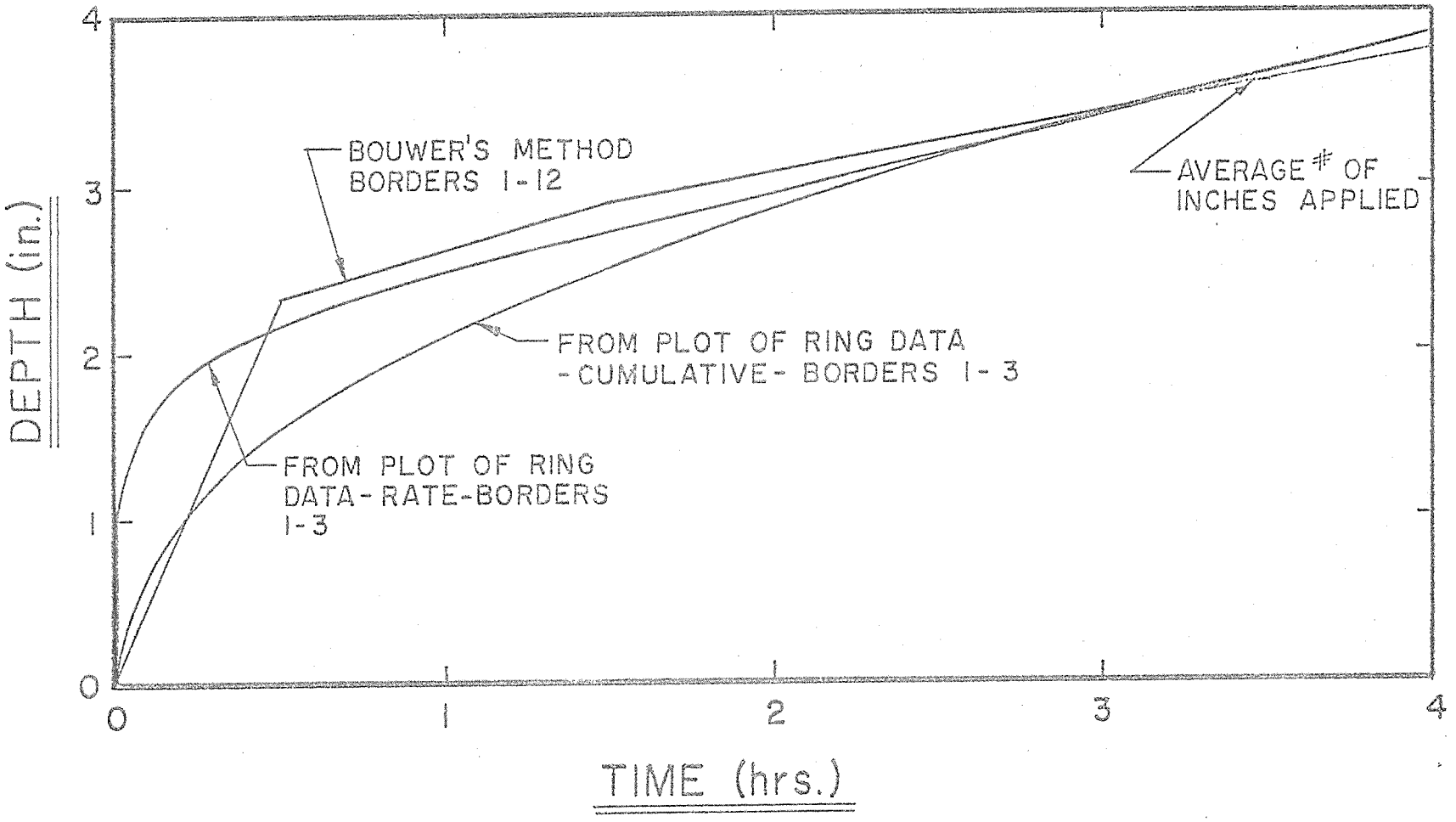


Figure 1. Cumulative infiltration functions for first irrigation at Cotton Research Center.

TITLE: DEPTH DETECTION AND TRANSMISSION FOR OPEN CHANNEL FLOW MEASUREMENT AND CONTROL DEVICES

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 78-11

INTRODUCTION:

A more serious effort has begun in trying to develop a reliable, simple, accurate, inexpensive depth sensing device (with no moving parts) for open channels and irrigation field studies. Several other research projects depend on accurate depth detection that can be interfaced with digital electronics. The work to date consists of two parts: development of probes or instruments whose properties can be related to water depth and a processor/controller to interpret these properties accurately and reliably, and to store data for laboratory and field testing and calibration.

DEVELOPMENT OF DEPTH DETECTION INSTRUMENTS:

Up to this point, we have been investigating general ideas and concepts and not specifics. Thus, there was very little documentation of what was done. The first concept tried was a capacitance probe with two metal, insulated rods. The water was the dialectric. The biggest problem here is that the dialectric constant is affected by the properties of the water, such as: electrical conductivity, salt content, temperature, suspended materials, etc. Using a fluid with controlled properties would probably be too difficult, so this idea was abandoned.

The next thing tried was a tight fitting steel rod inside a glass rod. The steel rod acted as one plate of the capacitor, while the water acted as the other plate, with the glass as the dialectric. This seemed to work fairly well. Stable readings were difficult to get due to changes in water conductivity, and due to the inaccuracies of the circuitry used. An oscillator was used to charge and discharge the capacitor. The output was a frequency which depended upon the capacitance of the probe. Both the oscillator and the frequency counter used were suspect, and considerable drift resulted. A nine-volt DC battery was used to power the circuit.

Next, a large glass tube was used and filled with a salt solution and the same size steel rod (very loose fitting). The previous size glass tubing was too small in diameter and too thick for the capacitance range of the oscillator. This probe was hooked up to an autodata nine data acquisition system. Preliminary investigations showed that the battery voltage was critical in determining the output frequency. Also, we found that the autodata nine time clock was not accurate enough to provide stable frequency measurements.

During the work with the autodata nine, a new type of probe was built in an attempt to greatly increase the value of the capacitance. This consisted of a dozen loops of teflon insulated wire wrapped around a plexiglass frame. Of course the same problems of stability existed as with the other probes. An additional problem was also encountered, that of hysteresis caused either by the water clinging to the wire as the water level dropped, or by the water being absorbed by the teflon. This property of teflon will have to be explored, particularly since many commercial depth probes use teflon coated rods. It is not known if a different type of teflon is used or not. This area will have to be studied further.

A microprocessor data acquisition system was built to obtain more reliable results from these probes. It took a lot of effort to make sure that the data obtained by the processor was not affected by the processor itself. The voltage to the probe circuit is now separately regulated. A hardware counter was added to avoid interference problems between the real time clock and the frequency counter software. It appears that most of the electrical noise has been eliminated from the processor circuitry. Several problems were encountered in switching from external AC or DC to internal DC for memory storage. With these improvements, a more stable oscillator integrated circuit chip was found and is now being used in the probe circuit.

A new type of probe was developed for further testing. A glass tube was filled with mercury. This new probe was tested in a constant temperature room. An overnight run was made while monitoring

the probe, the probe circuitry with a fixed capacitor, and a crystal source frequency. The crystal source channel data was constant, indicating that the processor is working well. The data from the fixed capacitor showed a trend almost identical to recorded air temperature fluctuations, and the probe showed a steady rising trend caused by a slow drop in the water level (leak). While the temperature fluctuations were small (< 4 F), this indicates some temperature stability in both probe and probe circuitry.

Curiously enough, it was also found that the laboratory source frequency showed a high degree of variability and was not reliable enough for this work.

One problem with these probes is that there is an end effect on capacitance at very low water levels. This may be caused in part by the location of the wire which is in contact with the water. During these experiments it has been placed in the water below the probe and out of the way. An alternative is to run a bare rod in the water parallel to the glass probe. This should eliminate the end effects, but may decrease the range and sensitivity. This will be tried in future experiments. Eventually it may be possible to mount the glass rod inside a metal tube at a set distance, and use this metal tube as the other plate of the capacitor, to transmit current to the water, and to protect the probe from damage.

All future work and testing will be documented according to the following procedure. A lab book will be kept to record data on each experiment including: the purpose of the test, specifics of the test including channel numbers, all plots made from the data, the date of the test, the location where the test was made, any other data taken (i.e. water depth measured, temperatures recorded), and the results of the test.

PROCESSOR/CONTROLLER DEVELOPMENT:

Purpose. A microprocessor controlled pulse counter has been designed to provide a portable system for data collection and testing of water level detectors with frequency output. (Note: water level detectors with voltage, current or other electrical output can easily be converted to frequency).

General Description. The system hardware consists of a microprocessor with over 21,000 memory locations, over 16,000 dedicated to data storage; a 32-channel pulse counter with four-digit accuracy; and a battery power supply to maintain the data memory during transportation.

The processor is programmed for two modes of operation. In the data input mode the processor sequentially scans the selected channels at a selected interval. After each channel is scanned the data is stored and displayed. Operating in the output mode the processor can be used to load or dump its memory or edit its memory as needed to output the data for processing. This mode is normally only used for dumping the stored data.

System Development. Development of this system required hardware and software development.

Hardware Development. A CRS-82 microprocessor system was purchased from Pro-Log Corporation to be the main controller for the system. The CRS-82 includes a CPU card (central processing unit), a 4-port input card, a 4-port output card, a card rack prewired for these cards, and a few additional memory and I/O (Input/output) cards. Spare slots are also included for custom design purposes.

A 16K (16,384) Byte (8 Bit Data word) memory card was added for data storage. Our use requires that the unit be transported from the data collection site to the processing site. Thus it was necessary to modify the Memory Board to provide power to the memory devices when the system power is turned off. The type of memory used is volatile, any power interruption causes the stored data to change, so power must continually be applied to the memory to maintain the data.

I encountered several problems with the data being changed when the power levels were changed by power surges caused by such things as turning on the displays and turning the AC power on and off. To solve this problem a

separate regulated power supply had to be added for the memory with special switching to avoid transients in the memory power circuits.

Problems were encountered when attempting to use the same program to monitor and update real elapsed time, and also to count and keep track of frequency data. To solve this problem, a hardware counter was developed to count and record incoming pulses. This counter starts and stops under program control. The final count is saved in the hardware counter and can be retrieved by the program when convenient. (Real elapsed time is the elapsed time from start of INPUT mode).

Interrupts used by the real elapsed time clock program are generated by an external hardware counter. The counter takes the crystal clock frequency from the CPU Board and divides it by 100 million to provide the interrupt frequency for the clock. Besides the interrupt pulse, and interrupt address must be generated to tell the processor where to go to start executing after an interrupt. The timing is such that the processor must acknowledge an interrupt before the interrupt address is placed on the processor address bus. If the timing is incorrect, invalid addresses will be presented to the memory, causing the program to fail.

All controls and displays are on the front panel with back panel connections provided for AC and DC power, teletype and RS-232 Input/output cables, and frequency inputs for each channel. The displays provide time from 000.0 to 999.9 minutes, two digits for channel number and four digits for the data.

Switches are provided for the following:

AC/DC power select

CHARGE/OPERATE (power on-off)

RESET (resets processor, take program out of INPUT and OUTPUT modes).

INPUT DATA (starts data collection program)

OUTPUT DATA (starts teletype monitor program)

MEMORY (provides power for memory when system is off)

Software Development. The MPS TTY monitor program from the Pro-Log Corporation is used to provide the communication required to output the data. The monitor program performs the operations of LOAD, DUMP, MOVE, TRANSLATE, and EDIT. The LOAD operation loads memory from the teletype paper tape. DUMP causes memory data to be printed or punched on the teletype. MOVE relocates blocks of memory within memory. TRANSLATE allows page addresses to be changed within page memory. EDIT allows manipulation of specified memory address by various commands, The EDIT command subset allows setting the memory address plus; listing, storing, substituting and executing data at the specified address. The memory address can also be incremented or decremented[1/].

Elapsed time is maintained by an interrupt controlled program. Each interrupt initiates the clock program thru subroutine vectors provided with each interrupt pulse. After an interrupt pulse is acknowledged by the processor the interrupt circuits provide the address of the clock subroutine to the processor. The clock routine increments its counters once before returning to the main program. The elapsed time is maintained in registers (memory) for the main program to access as needed. This program operates only during the INPUT mode.

In the main program, control for the counter and data handling is maintained. To control the counter an address is sent to the counter telling it which channel to count. Then the counter is reset and enabled for the count period. At the end of the count period a hold signal is sent to the counter to hold the count while the data is read.

1/ Program, 8080 Monitor
ProLog Corporation

After reading the data the processor stores the data and displays the contents of the memory locations so that the operator sees the actual data stored.

Scan intervals and the channels to be scanned are entered in ROM (Read Only Memory). To change these values a new ROM must be programmed and inserted into the processor.

Work Remaining. Several improvements can be made before going to the final field data acquisition system.

Thumbwheel switches may be provided for manual entry of first and last channels and for manual selection of the scan interval.

Temperature problems have been encountered during warm temperature operations. Extended temperature range integrated circuits will be added to hopefully solve this problem without the need for forced cooling.

Software changes will be made to provide one button output of data.

Software changes must also be made before field data collection is undertaken. The changes will allow the processor to determine when water has reached a probe. Data will be ignored at each probe until the arrival of water has been detected. In this way only actual water level data will be recorded, thereby conserving memory space.

SUMMARY:

Preliminary studies have been conducted in an attempt to develop simple, reliable, accurate inexpensive depth detection devices (with no moving parts) that can be interfaced with digital electronics for open channel flow measurement and control, irrigation automation control, and irrigation field data collection and processing. Initial testing of different depth sensing concepts indicated that precise control of voltage and frequency (time) were essential. Several depth sensing probes have been constructed and tested, and it appears that the objectives of this study can be met.

A microprocessor data acquisition system was built to provide for more reliable testing, calibration and data collection. The processor sequentially scans from 1 to 32 selected channels at predetermined intervals. After a channel has been scanned the data is stored and displayed. Only raw data is collected by this system. After data collection is completed the system may be easily transported to the computer facility for processing.

PERSONNEL: John A. Replogle, Albert J. Clemmens, Robert F. Allen

TITLE: MATHEMATICAL MODELING OF BORDER IRRIGATION HYDRAULICS

NRP: 20740 CRIS WORK UNIT: 5510-20740-003

CODE NO.: USWCL 78-12

INTRODUCTION:

Research over the last year has concentrated on the zero inertia model. This model represents the solution of the Saint Venant Equations with the inertial terms eliminated. The model seems to represent an equitable tradeoff between the time and cost involved with making a run, and the accuracy of the solution. In comparisons with field data, the model does reasonably well. However, it is difficult to determine if differences in results are due to model inaccuracies or errors in the input data. Field experiments are being performed under a different research outline in order to provide more information in this area. Improvements in the model continue to be made as more types of field conditions are considered.

DIMENSIONAL ANALYSES:

A more general form of dimensional analysis has been developed which can be used for a wider variety of situations, including both level basins and sloping borders. A graphical dimensionless solution of level basin advance (both before and after the irrigation stream has been cut off) has been developed and is in press. A solution for sloping border advance has also been developed and a manuscript is being prepared to present it and the general dimensional analysis. The simplicity of the dimensionless solution has made it possible to compare solutions from the zero inertia model and other methods. A dimensionless graphical solution of maximum water depths in level basins was prepared. This was compared to the solution presented by the Soil Conservation Service (SCS) in their border irrigation handbook. For an impervious bed, the SCS values were approximately 20% less than that calculated by the zero-inertia model. Infiltration was not considered in the SCS solution. For higher infiltration rates, the solutions became closer, and at even higher rates the SCS solution overpredicts water depth. A manuscript was prepared and is under review which presents the two solutions and their assumptions.

DESIGN AND MANAGEMENT OF LEVEL BASINS:

The dimensionless solutions that have been prepared above are not in a form that is convenient for use in design and management. For a given depth of application a trial and error solution would be necessary for the application time necessary (and/or flow rate) to get a given application efficiency. Also, considerable computation would be involved in obtaining a value for the application efficiency. In other words, the input to a physical model of the irrigation process is different from the input to a design and/or management aid. So rather than attempting to obtain these aids directly from the model, it is more convenient to solve the model in the usual way and then perform a dimensionless transformation to put these solutions in a more useful form. This has been done for one value of a, 0.5, and two different transformations made. The results of these are plotted in Figures 1 and 2. The parameter a represents the shape of the infiltration function or the slope on a logrithmic plot. The infiltration function is assumed to be a power function. To obtain solutions with Figure 1, the field length, unit flow rate and flow resistance values must be fixed. For Figure 2, the net depth of application, time necessary to infiltrate the net depth and the flow resistance values are fixed.

MANAGEMENT ON SLOPING BORDER:

The management on sloping borders (and basins) is much more difficult than on level basins. The reason for this is that on level basins, a higher flow rate will always give a greater possible application efficiency, while on sloping borders there is one flow rate that will give the greatest possible application efficiency for a given set of conditions. A flow rate either higher or lower will result in a lower potential efficiency. Also, changing field conditions change the optimum flow rate, making sloping border management quite difficult.

One approach to the problem is to attempt to analyze all of the variables which affect the optimum flow rate and using mathematical, empirical, or other solutions, determine a new flow rate time, (Q-T)

combination for each irrigation. This is obviously very difficult. A second approach is to use the hydraulics of the flow during the early part of an irrigation to determine the optimum Q-T combination. At this point in time, this method is not practical since the methodology and instrumentation have not been adequately developed.

A third approach, and the one used here, is to calculate optimum Q-T combinations for a range of values of the various parameters. The parameters that vary from irrigation to irrigation are the infiltration, the desired net depth of application, and the flow resistance. The effect of flow resistance will be ignored for the time being, and it will be assumed that the roughness does not change from irrigation to irrigation. Instead, the effects of infiltration, net depth of application and soil moisture storage will be evaluated.

Advance, recession and infiltration measurements were taken on the McDonnel-McElhaney farm on two separate days in 1977. During the first irrigation observed (5-26-77), the crop was starting to wilt, indicating water stress. This would probably represent the least soil moisture storage or the dryest conditions for an irrigation. During the second irrigation observed (6-9-77), the soil moisture was at a high level with visible moisture at the surface, representing the wettest conditions. The infiltration functions for these two conditions represent the two extremes in infiltration and soil moisture. It was estimated that the soil profile could store less than 1 inch of available moisture per foot of soil. Thus, with a 5-6 ft rooting depth, water applications should be on the order of 3-4 inches. The other particulars for this field are: field length = 610 ft, field width = 170 ft, field slope = 0.00033 ft/ft, the crop is alfalfa with a suggested Manning roughness coefficient = 0.15, and power infiltration functions with constants = 2.9 and 2.2 in/hr^a and powers = 0.60 and 0.52 for the dry and wet conditions, respectfully. (The border was blocked to prevent runoff). The two infiltration functions along with the SCS intake family for that soil type are shown in Figure 3.

The zero-inertia border-irrigation model was used to determine the maximum application efficiency and resulting uniformity for the two soil moisture conditions at 3 and 4 inches on net application and at 5 cfs intervals of flow rate. The results are presented in Tables 1 and 2. These efficiency values represent the maximum application efficiency (desired or net application/gross application) rounded to the nearest percent for whole minute application times with the criteria that no location receive less than 90% of the net application, and that 99% of the soil profile is filled based on the assumed net depth of application (99% storage efficiency). Note the high application efficiencies that are possible under the ranges of flow rate, net application and infiltration conditions.

It could be argued that the higher application (4 inches) would be more practical on the dry soil, and the lesser application (3 inches) on the wet soil. Thus the farmer could achieve an efficiency of 90% at any flow rate from 15-20 cfs. Also notice that there is a trend in the optimum flow rate. For the wet condition, applying more water changes the optimum from about 17 cfs to about 5 cfs. For the dry conditions, the change is smaller, from about 21-22 cfs to 18-19 cfs. Obviously, greater water applications require a lower flow rate to achieve the optimum efficiency for any soil moisture condition.

Caution should be exercised in utilizing these types of results for the following reasons: the effects of surface roughness were not analyzed, variations in slope or roughness could cause changes in calculated versus actual advance and recession, definitive information on intake versus soil moisture or intake versus tillage practices were not evaluated, and the actual soil moisture deficit was not evaluated in detail. This example does point to the possible utilization of irrigation modeling.

DEFINITIONS:

In March 1978, an informal conference on Surface Irrigation Modeling was held at the U. S. Water Conservation Laboratory. The conference participants agreed on the following definitions or categorizations for surface irrigation:

I. Border Irrigation:

A. Basin Irrigation

1. level

2. Sloping

B. Sloping Border Irrigation: This terminology is preferred to graded border. A border strip is the area of land irrigated.

1. blocked end: This method can have varying degrees of ponding. The difference between a ponded, blocked-end border and a sloping basin is the intent of the manager.

2. open-ended

a. runoff lost

b. runoff reused or pumped back

II. Furrow Irrigation:

A. Level Basin Furrow Irrigation

B. Sloping Furrow Irrigation: Again, sloping is preferred to graded.

1. runoff lost

2. runoff reused or pumped back

SUMMARY:

Continued work with the zero-inertia border-irrigation model has been very worthwhile. The model gives realistic solutions under a wide variety of conditions. It has been shown that the model can be made usable for helping to properly manage water in irrigation borders and basins. Dimensional analyses have been useful in helping to display the model results graphically for easier use.

PUBLICATIONS;

1. Clemmens, A. J. Discussion of: "Dimensionless Solutions of Border-Irrigation Advance," by N. K. Katopodes and T. Strelkoff [Jour. Irrig. and Drain. Div., Proc., Amer. Soc. Civil Eng. 103(IR4):401-418. 1977]. Jour. Irrig. and Drain. Div., Proc., Amer. Soc. Civil Engin. 104(IR3):339-341. 1978.

2. Clemmens, A. J., and D. D. Fangmeier. Discussion of: "Border-Irrigation Hydraulics with Zero Inertia," by T. Strelkoff and N. D. Katopodes [Jour. Irrig. and Drain. Div., Proc., Amer. Soc. Civil Engin. 103(IR3):325-342, 1977]. Jour. Irrig. and Drain. Div., Proc., Amer. Soc. Civil Engin. 104(IR3):337-339. 1978.

3. Clemmens, A. J., and T. Strelkoff. Dimensionless advance for level basin irrigation. Jour. Irrig. and Drain. Div., Proc., Amer. Soc. Civil Engin. (In press).

4. Clemmens, A. J. Verification of the zero-inertia model for border irrigation. Trans. Amer. Soc. Agric. Engin. (In press).

5. Fangmeier, D. D., and T. Strelkoff. Mathematical Models and Border Irrigation Design. Presented at the June 27-30, 1978 American Society of Agricultural Engineers Summer Meeting, held at Logan, Utah (ASAE Technical Paper No. 78-2007).

6. Strelkoff, T. Flow with Equilibrium in Border Irrigation. Jour. Irrig. and Drain. Div., Proc., Amer. Soc. Civil Engin. (In press).

PERSONNEL: Albert J. Clemmens, John A. Replogle, Allen R. Dedrick

TABLE 1. MAXIMUM APPLICATION EFFICIENCIES FOR DRY CONDITIONS.

MAXIMUM EFFICIENCY (%)

NET APPLICATION	FLOW RATE (CFS) 10	15	20	25
3"	70	74	77	76
4"	87	92	96	90

UNIFORMITY

NET APPLICATION	FLOW RATE (CFS) 10	15	20	25
3"	.90	.93	.93	.97
4"	.94	.98	.98	.96

APPLICATION TIME (MIN)

NET APPLICATION	FLOW RATE (CFS) 10	15	20	25
3"	62	39	28	23
4"	66	42	30	26

TABLE 2. MAXIMUM APPLICATION EFFICIENCIES FOR WET CONDITIONS.

MAXIMUM EFFICIENCY (%)

NET APPLICATION	FLOW RATE (CFS)			
	5	10	15	20
3"	79	87	90	90
4"	94	85	80	80

UNIFORMITY

NET APPLICATION	FLOW RATE (CFS)			
	5	10	15	20
3"	.90	.97	.97	.99
4"	.98	.93	.92	.91

APPLICATION TIME (MIN)

NET APPLICATION	FLOW RATE (CFS)			
	5	10	15	20
3"	111	50	32	24
4"	122	68	48	36

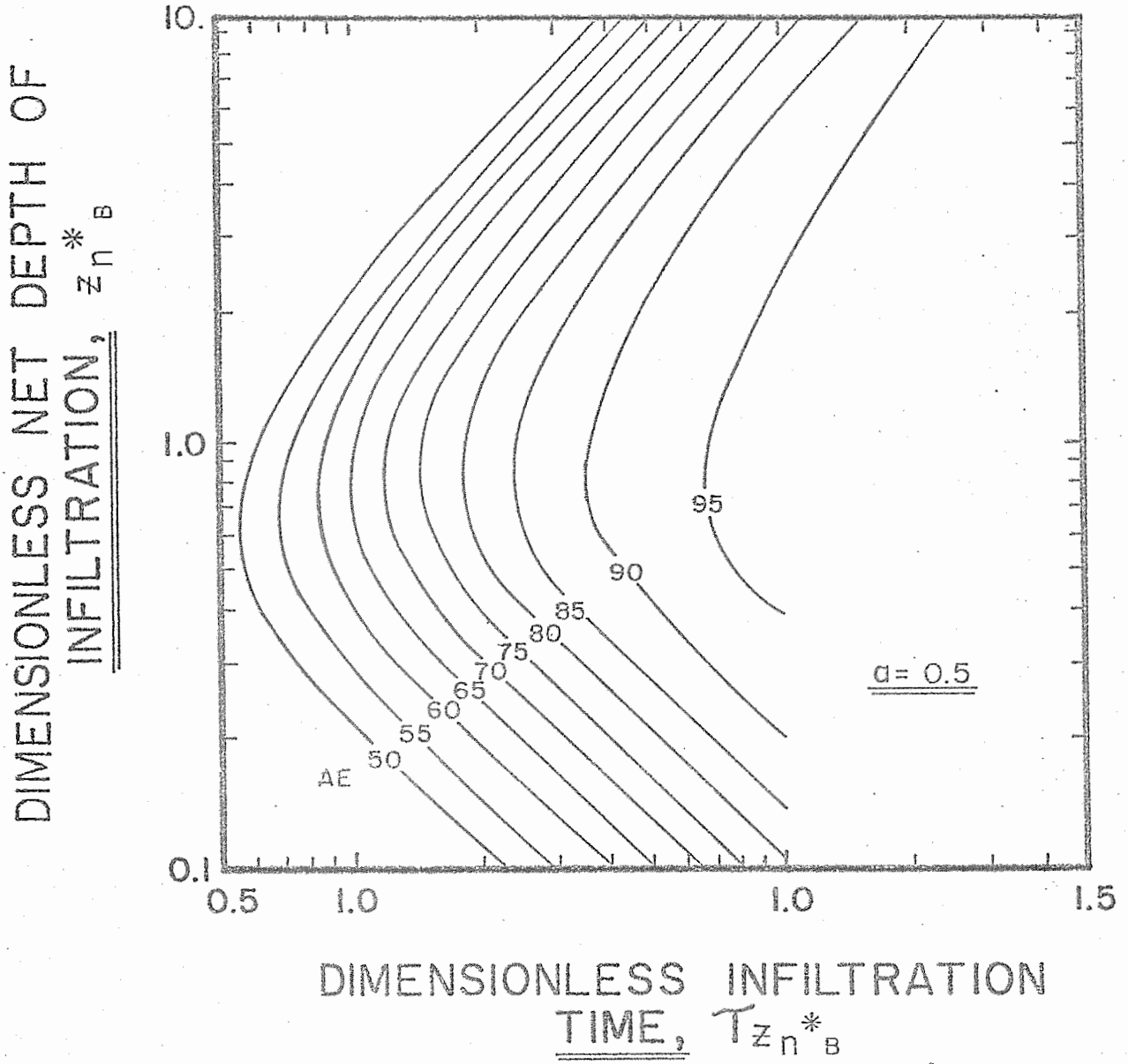


Figure 1. Level basin application efficiencies (AE) representing variations in infiltration and soil moisture deficit, a = 0.5.

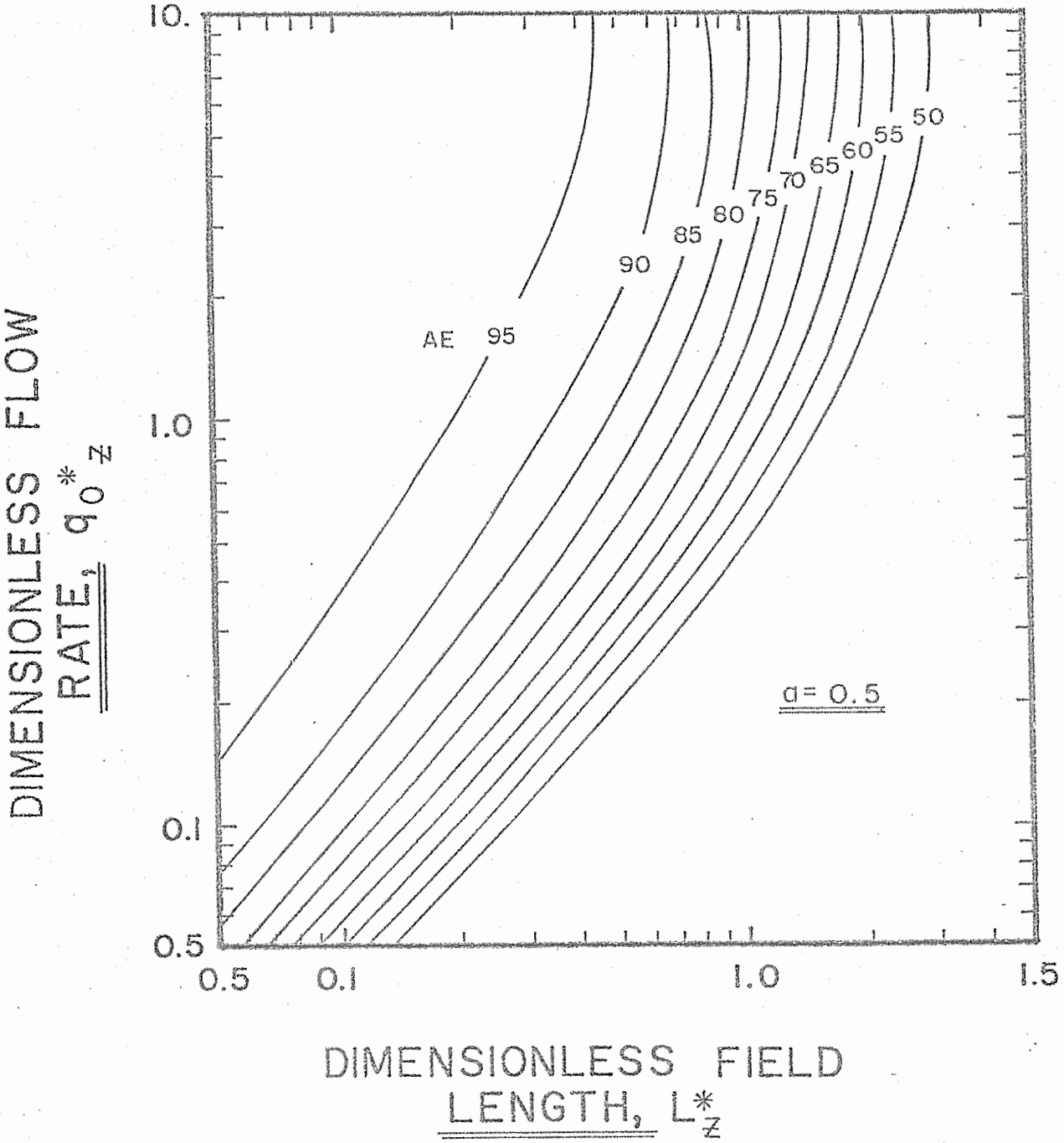


Figure 2. Level basin application efficiencies (AE) representing variations in flow rate and field length, a = 0.5.

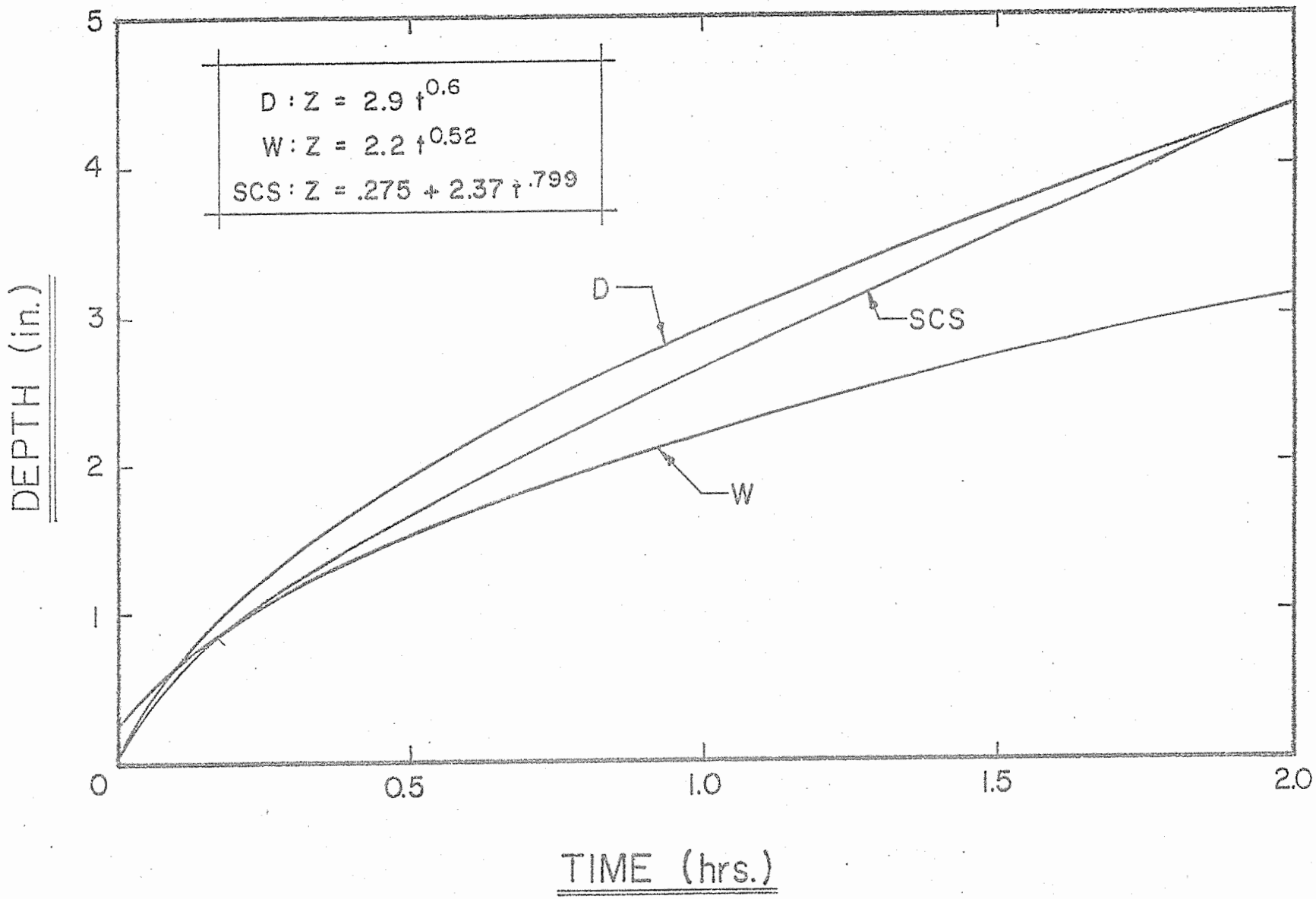


Figure 3. Cumulative infiltration functions for wet (W) and dry (D) conditions on McDonnel-McElhaney farm.

TITLE: COMPUTER SIMULATION OF GREENHOUSES

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: Ariz.-WCL 70-1

SUMMARY:

Progress was made in writing and debugging subroutines for the "modular energy balance" (MEB) program. As described in the 1977 Annual Report, the modules or subroutines each simulate the performance of some energy-related device. Patterned after a TRNSYS program from the University of Wisconsin, the modular energy balance program is highly versatile because the user specifies at run time which of the devices he wishes to include in a particular run and how they are connected (wires and pipes) together. The program has virtually no size limit as implemented on the USWCL minicomputer because the subroutines are stored on the disk as overlay modules.

During the past year, a "simple" greenhouse model subroutine was debugged. In this model, only solar, wall conduction, ventilation and external (i.e., heater) fluxes are considered. The greenhouse dry bulb air temperature is computed non-iteratively, so this routine should be useful when fast, crude estimates of energy use are needed.

Also a "complicated" model greenhouse was debugged which was based on the mathematical greenhouse model developed at the start of this project. The model computes outside cover temperature, inside cover temperature, vegetation temperature, soil temperature, air temperature, and air humidity ratio. It can be used to obtain a detailed energy balance involving more than 20 fluxes of heat and moisture.

A mathematical model of a night sky radiator with a selective surface was developed, and the corresponding subroutine debugged. It will be used to predict the feasibility of such a device for dumping excess greenhouse heat to the night sky.

Another subroutine has been written but not yet debugged to simulate the performance of air to water heat exchangers that can alternatively be wet or dry as would be the case during a diurnal cycle in a greenhouse.

The list of devices for which subroutines have been written now includes: reader, integrator, printer, thermostat, differential thermostat, pump or fan, tee-diverter-mixer, dry heat exchanger, wet heat exchanger, solar collector, water tank, time function, reservoir, simple greenhouse, complicated greenhouse, heater, and night sky radiator.

PERSONNEL: B. A. Kimball

TITLE: GROWTH AND YIELD OF JOJOBA (SIMMONDSIA CHINENSIS (LINK) SCHNEIDER) ON RUNOFF-COLLECTING MICROCATCHMENTS

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: USWCL 73-4

INTRODUCTION:

For background information, refer to the Annual Reports from 1973 through 1977. Three papers summarizing the study are: (1) "Growth and Yield of Jojoba Plants in Native Stands Using Microcatchments," by W. L. Ehrler, D. H. Fink, and S. T. Mitchell. 1978. Agron. J. 70:1005-1009; (2) "Yield Improvement of Jojoba by Runoff Farming," by W. L. Ehrler and D. H. Fink. 1978. Proc. of the Third Internat. Conf. on Jojoba, Riverside, California (In press); and (3) "Runoff Farming for Jojoba," by D. H. Fink and W. L. Ehrler. 1978. Proc. of the Internat. Arid Lands Conf. on Plant Resources, Lubbock, Texas (In press).

PROCEDURE:

Rainfall and runoff were measured for every storm throughout the year. Periodic measurements were made throughout the year of soil moisture with the neutron meter and of plant water potential with the Scholander pressure chamber, both sets of data being taken simultaneously on the same plot. Seed yield was obtained by hand picking in June and plant canopy volume was measured in November.

RESULTS:

Runoff as Related to Rainfall and Soil Treatments. Although the summer rainfall of 1978 (July-September) was about average, the fall rainfall in the first three months of the 1978-1979 growing season (October-December) equalled or exceeded the normal yearly average for the site (Table 1). Treatment T_2 continued to give a high runoff efficiency, averaging 89% runoff over the whole year, which resulted in a water delivery to the plant almost six times that received as rainfall by the control. This value contrasts with the 52% figure for T_1 (which had been converted to a clay-NaCl treatment in August 1977). The runoff percentage for T_1 is only moderately higher than the mean value for bare soil. Nevertheless, from October-June the T_1

treatment delivered over four times as much water to the plant as the control received (883 versus 211 mm), as compared with an average of three times as much in previous years with bare soil.

Soil Water Storage

Neutron meter readings taken at approximately monthly intervals documented a consistently higher soil water content (Θ_v) in treatments T_1 and T_2 than in the control (T_0) during most of the flowering and fruit setting season, i.e., from about mid-February to mid-May (Figure 1). No significant differences were apparent in Θ_v between T_1 and T_2, despite the considerably greater amount of water delivered to the plant in T_2 plots. In spite of the extra water storage in T_1 and T_2, Θ_v in all three treatments underwent the usual precipitous decrease from mid-February to harvest time in late June. No measurements were made during the summer rains. The winter rains brought Θ_v up to field capacity in all treatments, but with a considerable lag for the controls.

Plant Water Potential

Plant water potential (Ψ_{plant}) data (Figure 2) reinforce the pattern shown earlier in Θ_v, viz., that the level of plant hydration was greater in T_1 and T_2 than in T_0. The differences, although not large, were consistent over the whole flowering and fruiting season, and were in the same order as the final seed yield: greater hydration and seed yield as Θ_v increased. Sufficient numbers of simultaneous measurements of Ψ_{stem} and Θ_v were made that a regression line was drawn through the plotted data points (Figure 3). The data show that maximum plant hydration (least negative value of Ψ_{stem}) occurs when Θ_v is around 12% (the field capacity). Only slight decreases in Ψ_{stem} occur with decreases in Θ_v until about 6%, below which point Ψ_{stem} decreases steeply with further small decreases in Θ_v, until -80 bars is reached (when Θ_v is 3.8%). This curve is similar in shape to those for mesophytes.

Plant Growth

The main trend obvious in the growth rate as judged by canopy volume is the higher rate for T_2 than the other treatments (Figure 4).

Another point is the difference in plant volume between T_0 and T_1 that did not appear until 1978, coinciding with the conversion of T_1 from bare soil to clay-NaCl in August 1977, and the subsequent gain in water delivered to the plant.

Seed Yield

As shown in Figure 5, the seed yield was significantly higher in T_1 than T_0 for the first time. Also, the yield for T_2 was significantly greater than that for either T_1 or T_0. The yield per plant for 1978 was: T_0, 74 g; T_1, 204 g; T_2, 282 g, each value being the mean of 10 replications. The maximum yield was from a T_2 plot, 682 g. Increasing plant size in time should steadily contribute to larger yields.

Extension of Runoff Farming to Crops Other Than Jojoba

I. Christmas Trees

INTRODUCTION:

The source of Christmas trees in Arizona is almost exclusively imports from other states, primarily Montana. If a method for growing these trees locally could be devised, it would provide more income for Arizona growers. Growth rates at desert elevations would be faster than in the high country, but the lack of adequate rainfall is a problem. Irrigation is an answer, but an expensive one, since the trees would have to compete with high income crops like cotton and citrus on expensive land and would require increasingly costly water. Growing the trees on lower cost land without irrigation is an attractive alternative to irrigation if adequate water can be supplied to the crop, and provided that the crop is sufficiently drought tolerant to withstand the inevitable rainless periods. Runoff farming is a method that multiplies the rainfall by use of sloping catchments that deliver extra water to a plant, thus augmenting soil water storage.

The present status of runoff farming technology makes it likely that simple, low-cost catchments can be utilized in low rainfall regions to attain the fast growth rates characteristic of desert climates, thus leading to the production of a suitable Christmas tree

in three or four years. Accordingly, a pilot experiment at Granite Reef was designed to test this hypothesis by growing Christmas trees without irrigation in a 230-mm rainfall region at an elevation of 400 meters.

PROCEDURE:

The design is five rows, with five plots per row, totaling 25 plots, 4.9 m on a side, with a level 4-m^2 sunken, triangular section of the square designated as the plant area (Figure 6) in which plot No.'s 1-25 inclusive are used in the present experiment). The rest of the square serves as the 20-m^2 catchment, which has sufficient slope to direct water to the plant. Thus the ratio of catchment to growing area is the same as that used successfully with jojoba, 5:1. The treatments consist of different types of coatings on the catchments, as follows: (1) bare, smoothed, compacted soil, (2) paraffin wax, known to have a runoff efficiency of 90%, and (3) clay-NaCl, expected to have about 50% runoff efficiency. A fertility variable will be initiated after the trees begin fast growth, consisting of five plots in each of treatment No.'s 2 and 3 that will be given nitrogen fertilizer and five others left unfertilized. The trees with the bare soil catchment will not be fertilized.

Seedlings obtained from the Arizona State Land Department were transplanted to the Granite Reef test site to a gravelly soil of low water holding capacity on 24 February 1978, with one seedling per plot. The mean height was 15.1 cm with a mean stem diameter of 1.60 mm. Each was irrigated with 10 ℓ of water immediately after transplanting. A wire mesh basket with a flap of burlap on the top was placed over each seedling for protection from animals and sunshine at noon. Neutron meter access tubes were installed to a depth of 140 cm in all five plots in the third row, with each of the five treatments being represented. On 30 June clay and NaCl were incorporated in the upper 2 cm of soil of the catchments at the rate of 63.5 T/ha and 11.4 T/ha, respectively, in 10 of the 25 plots. Tensiometers were installed in two plots at depths of 15 and 30 cm. The plants were irrigated by hand until the summer rains began. In

addition to the initial irrigation at transplanting, 10-ℓ irrigations were given on the following dates: 3, 16, and 30 May, and 14 June. A low berm was constructed around each plant to confine the water primarily to a 5000-cm^2 area, such that the application of 10 ℓ amounted to 20 mm of water. On 19 September 10 plots were sprayed with a mixture of melted paraffin @ 0.5 kg wax/m^2 and an antistripping agent to decrease the amount of paraffin to one-half the usual rate. Between the transplanting date, 24 February and 25 July, when all plots were compacted with a mechanical vibrator-compactor, plants on the 15 plots with untreated catchments became established with 100 mm of irrigation water and a total of 390 mm of runoff (including that from the 50-mm rain that fell on 24 July, thus permitting good compaction the following day). The runoff was estimated assuming that the bare soil catchments collected the same percentage of rainfall as a large plot of bare soil nearby which was accurately monitored. The 10 plots that were treated with clay and NaCl on 30 June may have collected somewhat more than 390 mm of rainfall, but probably not very much more, because they had not been compacted yet.

The heavy rainfall just before the plots were compacted (50.7 mm on 22 July and another 5.3 mm on 24 July) and subsequent rains of 18.5 mm on 2 August and 6.6 mm on 3 August resulted in a reasonably high value of volumetric soil water content (Θ_v) in all five treatments, ranging from 0.12 to 0.19 cm^3/cm^3 (Figure 7). After a long drought, Θ_v decreased to low levels, ranging from 0.048 to 0.109 cm^3/cm^3 on 5 October, despite two small rains (6 mm on 16 September and 4 mm on 23 September). The Θ_v data for 26 October were somewhat higher in the bare soil and clay plots than on 5 October, due to two rains, 10.7 mm on 21 and 22 October and 5.1 mm on 24 October. By contrast, Θ_v for the two plots with wax catchments, which had been treated on 20 September, were dramatically higher (0.236 and 0.171, an average increase of 0.12 from the previous measurement). This difference in soil water storage reflects the high runoff efficiency of paraffin wax as compared to clay or bare soil catchments. If one uses the 90% efficiency obtained repeatedly with wax in other tests,

the calculated runoff from the 20-m^2 catchment was 193 ℓ from the rain on 21 and 22 October. Provided that the water delivered to the growing area was evenly distributed, the total increment was 59 mm, a good irrigation. At the time of the last measurement of the year, on 21 November, the wax treatments had the highest Θ_v, the clay the lowest, and, surprisingly, the bare soil an intermediate level.

Twelve of the 25 plants developed a needle burn during the summer, and the plant in Plot No. 9 died. It was replaced with one from the original stock of plants that had been kept in the greenhouse. On 5 October a visual rating indicated that 16 of the 25 trees were showing significant needle elongation.

CONCLUSIONS:

It is encouraging that 24 of the 25 transplants survived the summer with only four small irrigations (20 mm each) beyond transplanting. Above average rainfall probably helped survival. Nevertheless, the low soil water content in early October, the development of a leaf burn, and the death of one plant all attest to the environmental adversity of the Granite Reef site. It thus appears that the Quetta pine has lived up to its reputed drought tolerance. When the weather warms up, growth should accelerate from numerous meristems present along the trunk of each tree.

II. Horticultural Crops

INTRODUCTION:

Israeli experience showed that under certain conditions runoff farming can be applied to crops other than desert natives, e.g., apricots and peaches. It was decided to set up a demonstration plot with several kinds of horticultural crops in an attempt to find varieties adapted to the rigors of runoff farming under southern Arizona desert conditions.

PROCEDURE:

A plot of ground about 10 x 36 m was cleared within the fenced jojoba experimental area at Usery Pass. A small tractor ("Bobcat") was used to construct a block of 12 plots (each 4.89 m on a side) with about a 5% slope from the edges toward the center of the plot

and an overall 5% slope at right angles to the slope of the individual catchments (Figure 8). Excavation to a depth of 10 cm of a semi-circular area at one edge of the square provided a 4-m^2, level plant growing area which received extra rainwater from the catchment formed by the rest of the plot. Therefore, the ratio of catchment to growing area was 5:1, the same as had been used successfully earlier for jojoba at Usery Pass and was being used concurrently for Quetta pines at Granite Reef.

There were two rows, each with six plots and a path between the rows that had the dual function of providing access to and drainage of excess water away from the experimental plots. Transplanting was on 31 January 1978. In addition to a 5-gallon size olive tree, there were the following bare root plants: grape (Black Monukka, Perlette, and Cardinal), fig (Black Mission), almond (Texas Mission, Ne Plus Ultra, and Nonpareil), pomegranate (Wonderful), apricot (Royal), and peach (Desert Gold). On 8 February, a root sprout of a jujube tree was dug from an orchard and transplanted to the remaining experimental plot at Usery Pass. Tensiometers were installed in the plots of grape (Cardinal only) and peach at depths of 15, 30, and 60 cm.

Plant Preparation, Irrigation, and Fertilization. Conditions were favorable for transplanting on 31 January, since a light rain was falling. To help insure that the roots made good contact with soil, each of the 11 plots was irrigated with 22 ℓ of rain water collected in barrels at the jojoba site. The same amount of tap water from the Laboratory was used on 8 February to irrigate the jujube plant after it was transplanted. Rain was adequate during the spring. However, by 3 April the apricot was wilting, and it was irrigated with 19 ℓ of runoff water. Subsequent irrigations were given to the plants on the following dates: 3 April, 19 ℓ to the apricot; 26 April, 20 ℓ to all 12 plots to solubilize the ammonium sulfate (9.8 g N per plot) broadcast over the growing area; 16 May, 20 ℓ to all plots to solubilize the added ammonium sulfate (9.8 g N per plot) and phosphoric acid (4.5 g P per plot); and 20 ℓ per plot on 30 May, 14 June, and 17 July. No further irrigations were given.

On 25 July, after a 13-mm rain, all plots were compacted with a mechanical vibrator-compactor.

RESULTS:

On 8 February small buds appeared on the pomegranate and peach. Growth was initiated at different times among the other species, but by 23 March all plants had leafed out. By June several plants had been damaged by pests, including the eating of leaves of the grape vines, apparently by rabbits, cutter bee leaf damage to the peach, and leaf consumption by grasshoppers on several tree species. The fig developed a leaf burn. By 11 August the apricot and peach were leafless, due partly to drought, but probably more to grasshopper damage; these two species did not survive. After being enclosed in wire cages, the grapes regenerated a new canopy.

Measurements made of the soil water content (Θ_v) to a depth of 140 cm showed no significant differences between the two species chosen to represent the whole area, the peach and the Cardinal grape. The average Θ_v for these two indicator plots was as follows: 18 August, 0.10; 5 October, 0.086; 26 October, 0.134; 21 November, 0.124. Although only the reading for 5 October was low enough to have caused a water stress, it is likely that Θ_v had decreased to low values in May and June. The combination of water stress and pest damage resulted in a stressful environment.

CONCLUSIONS:

The fact that 10 of the 12 plants survived the first year is a reflection of the hardiness of the species chosen for this test. However, mere survival is not sufficient. The test should be continued until fruit production is achieved.

PERSONNEL: W. L. Ehrler and D. H. Fink

Table 1. Rainfall-runoff accumulated on 4-m^2 plant growth areas by the three catchment treatments (T_0, T_1, T_2) by season (3 months summer rainfall season and 9 months growth and fruiting season).

Period	July-September			October-June[1/]			12-Month Total		
	T_0	T_1	T_2	T_0	T_1	T_2	T_0	T_1	T_2
	mm								
1973-74	-	-	-	108	372	642	-	-	-
1974-75	66	204	366	218	654	1236	284	857	1602
1975-76	55	190	289	189	504	1068	243	694	1357
1976-77	59	142	316	100	210	560	159	352	876
1977-78	75	210	366	358	1328	2023	434	1535	2389
1978-79	72	204	381	(211)	(883)	(1221)	(283)	(1087)	(1602)

1/ Experiment started in November 1973; no rain was recorded for October 1973 at a nearby weather station.

( ) 1978 data only; six months data of 1979 not included.

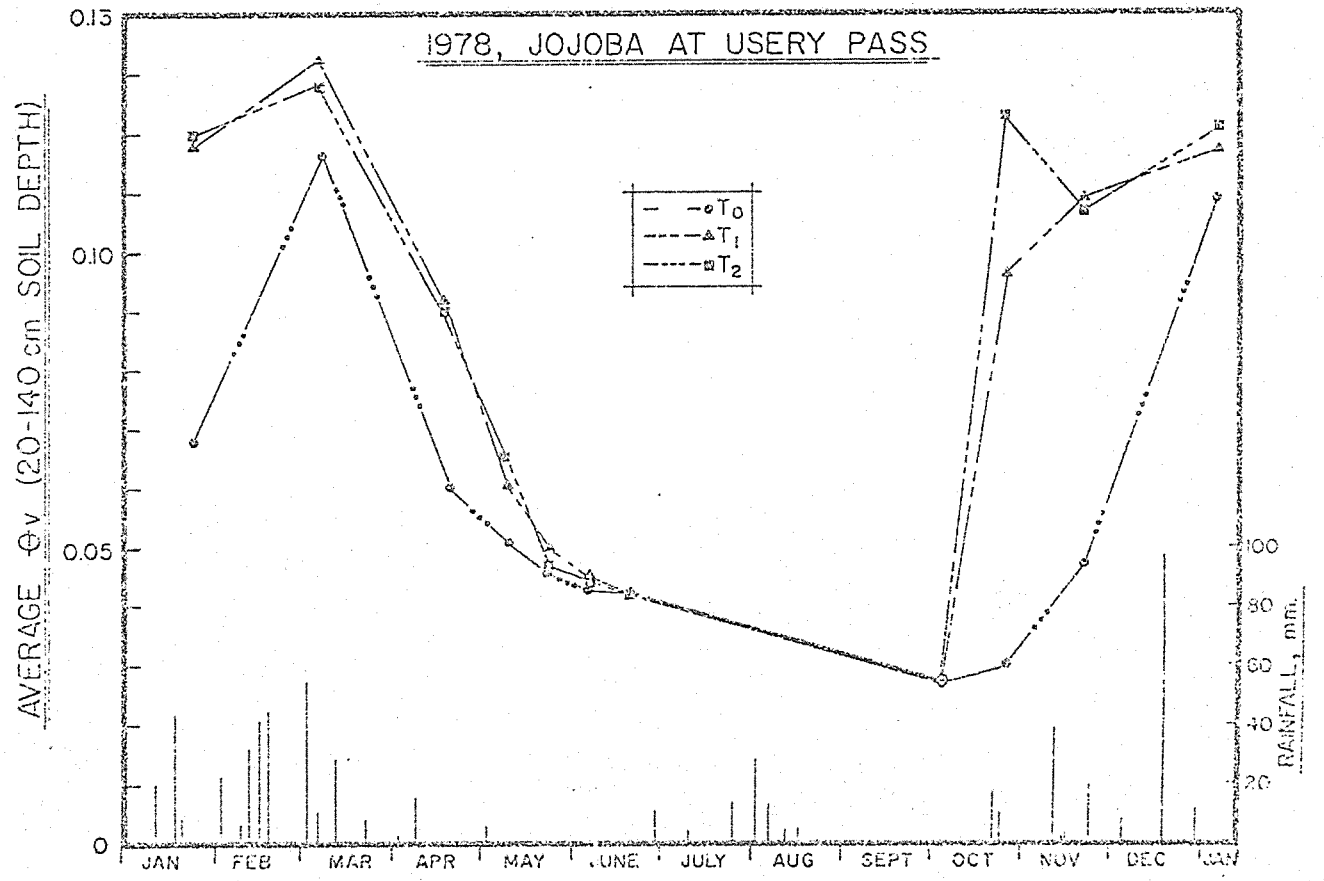


Figure 1. The yearly course of the average volumetric soil-water content, Θ_v, cm^3/cm^3) in the runon area, integrated over the depths of 20 to 140 cm, by treatments, in response to the indicated amounts of rainfall.

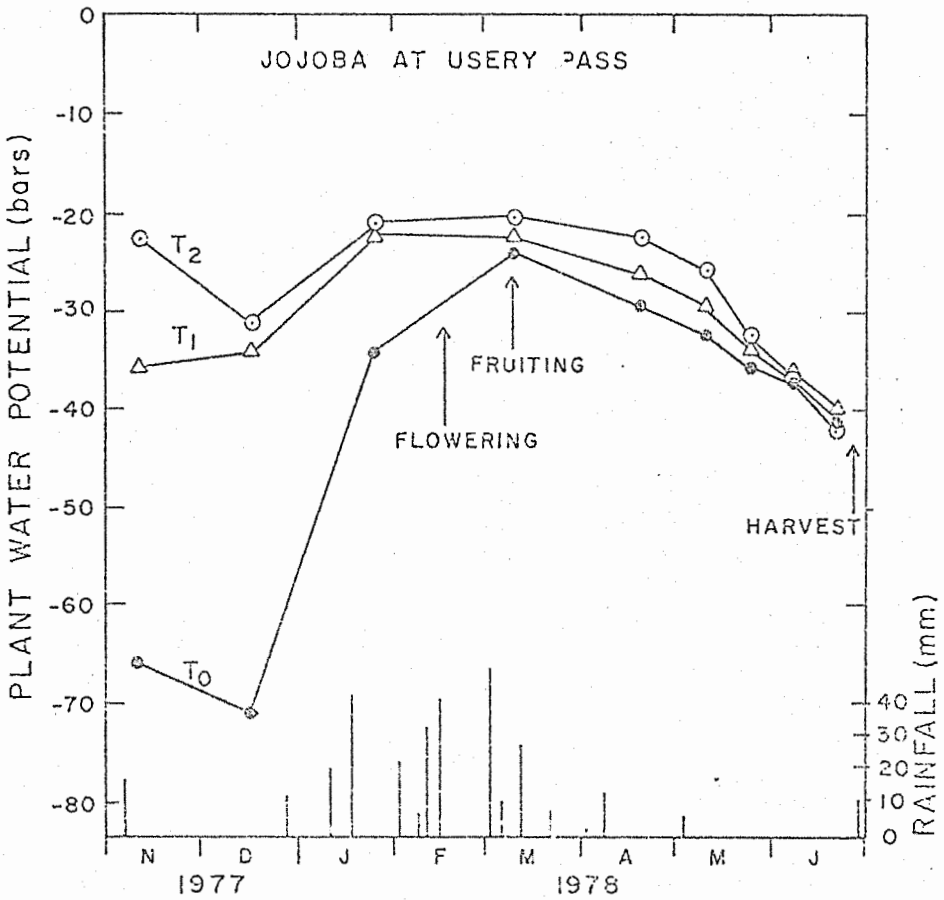


Figure 2. The yearly course of the mid-morning plant water potential of jojoba, by treatments (in response to the indicated amounts of rainfall).

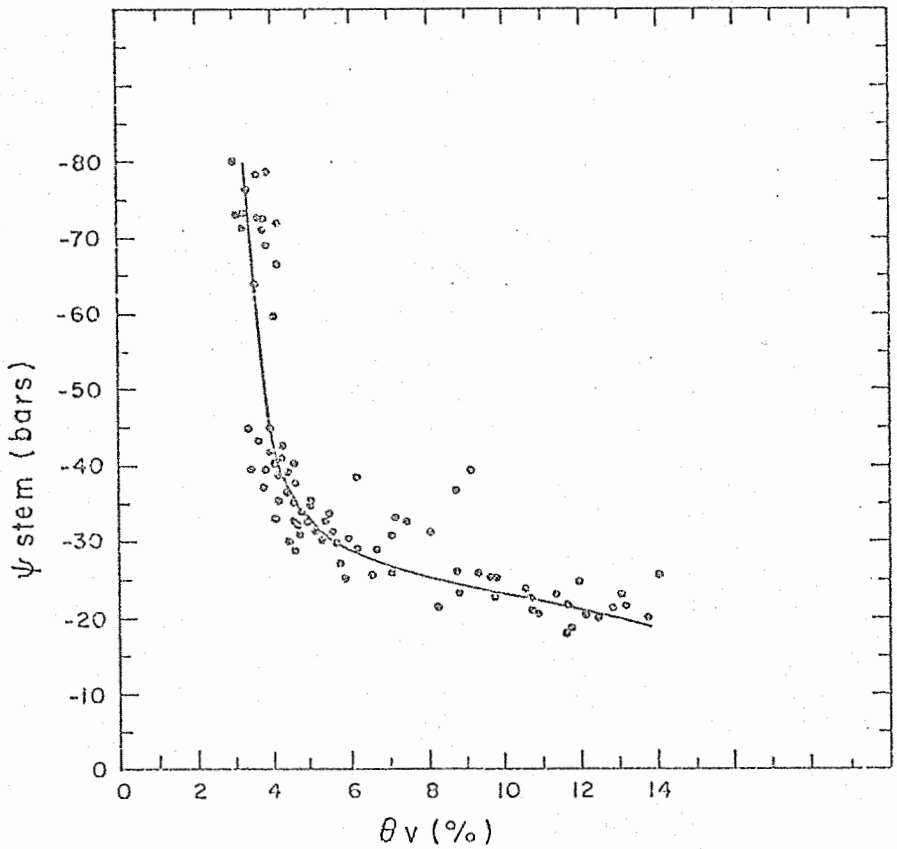


Figure 3. Values of the stem water potential (Ψ_{stem}) as a function of the soil water content (Θ_v) averaged over the 20-140 cm depth. Included are data from nine plants (three plants for each of the three treatments T_0, T_1, and T_2) from 10 sampling dates extending from 28 June 1977 to 20 June 1978.

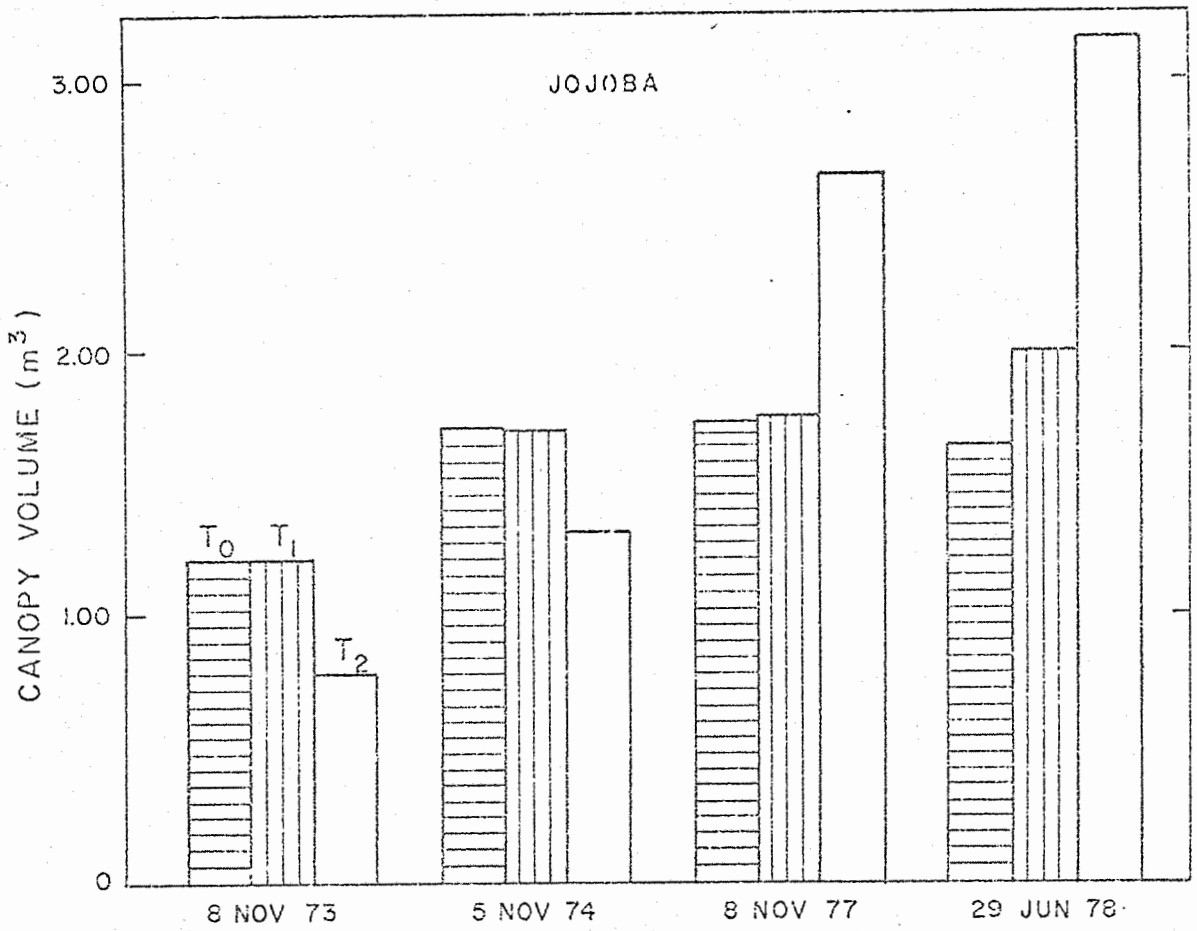


Figure 4. Jojoba canopy volumes from 8 November 1973 through 29 June 1978, by treatments.

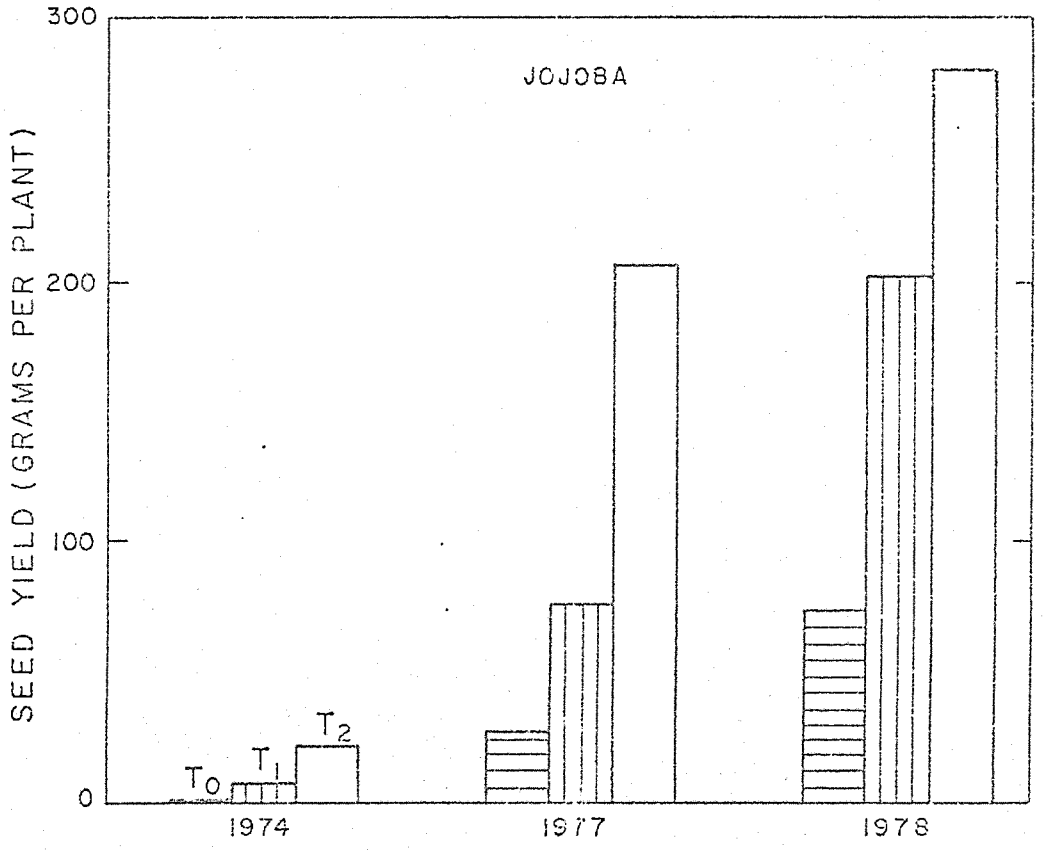


Figure 5. Jojoba seed yield in 1974, 1977, and 1978 as a function of treatment.

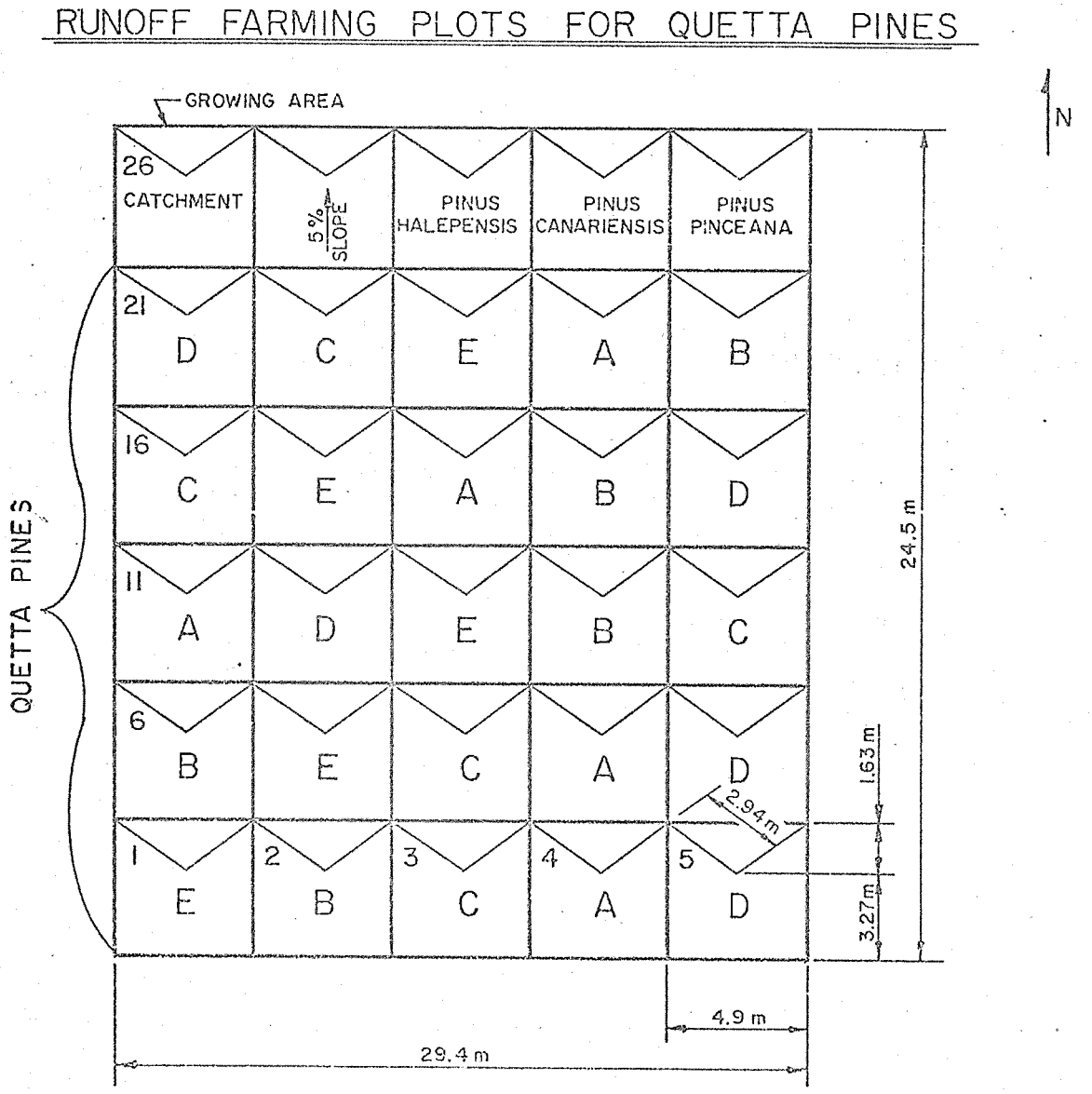


Figure 6. Plot diagram for the Quetta Pine experiment at Granite Reef, showing a 20-m^2 catchment and a 4-m^2 growing area providing a planting site for one tree in the center of the triangle.

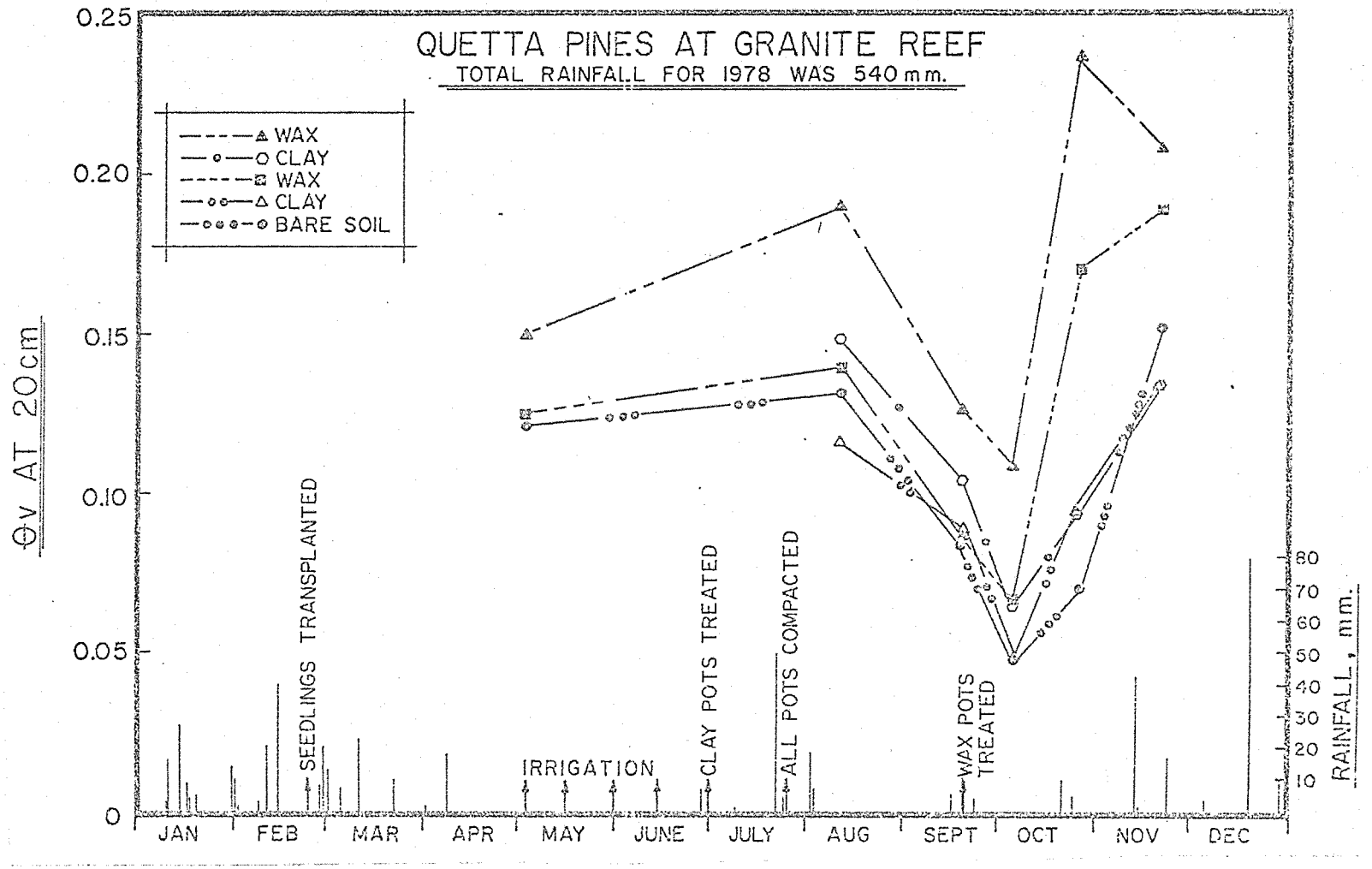


Figure 7. The yearly course of soil water content at the 20 cm depth as affected by (1) type of catchment: two each of wax and clay and one of bare soil; (2) rainfall, and (3) irrigation.

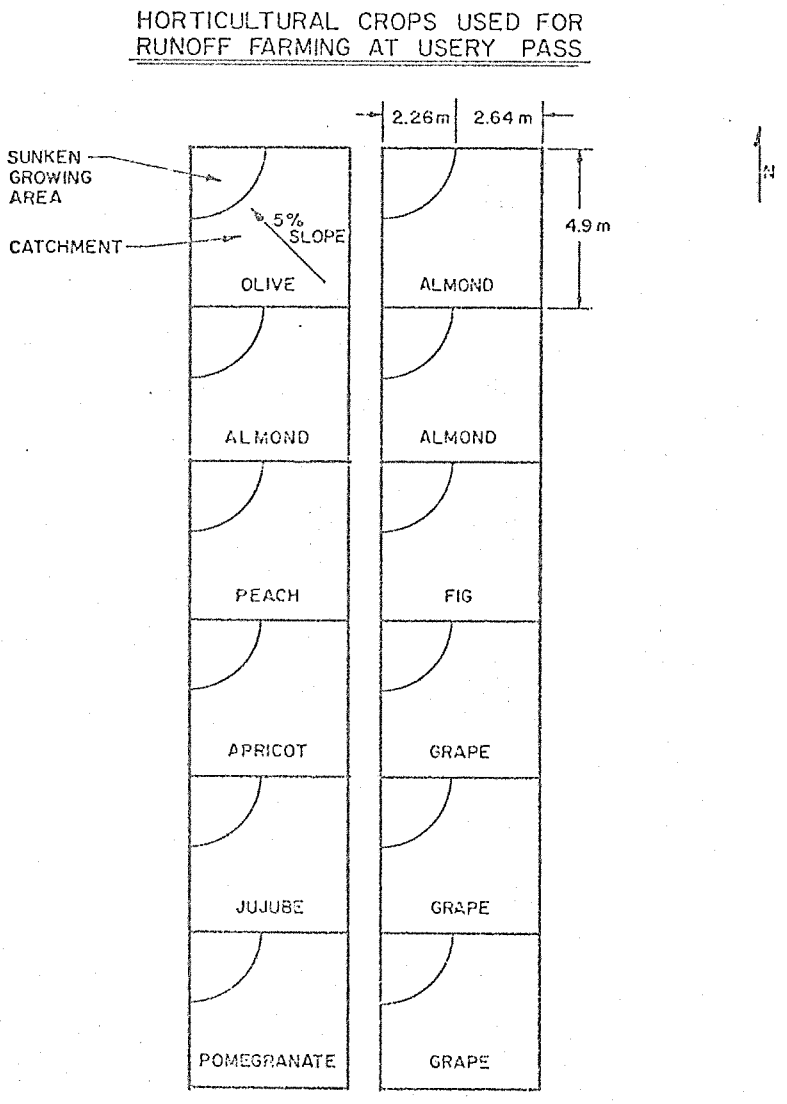


Figure 8. Plot diagram for the pilot test of runoff farming with horticultural crops at Usery Pass, showing a 20-m^2 catchment and a 4-m^2, compact growing area with space for a centrally located plant.

TITLE: DEVELOPMENT OF REMOTE SENSING TECHNIQUES FOR AGRICULTURAL WATER MANAGEMENT AND CROP YIELD PREDUCTION

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: USWCL 77-1

Research conducted under this outline consisted of relating spectral reflectances and canopy temperatures to crop water stress and yields. Experiments were conducted at two sites; Dunnigan, CA and at the USWCL at Phoenix. Field aspects of the Phoenix experiment consisted of growing two varieties of wheat (Produra and Anza) and one variety of barley (Briggs). The crops were planted across irrigation plots so that the three varieties received 6 different irrigation treatments, ranging from well watered to no irrigations. At Dunnigan, a 720-acre farm planted entirely to Briggs barley was used for extensive ground and airborne temperature measurements. This experiment was planned in conjunction with the Heat Capacity Mapping Mission satellite. However, the satellite launch was delayed until April 26, 1978, and started taking data after our field was harvested. The experiments will be discussed in three parts: (A) Spectral reflectance experiments at Phoenix; (B) Temperature-yield relationships at Phoenix; and (C) The Dunnigan experiment.

PART A:

Part of our research was directed towards developing two new remote sensing approaches to yield modeling in small grains. During 1977 and 1978, we measured the spectral reflectances of grain crops in the four Landsat wavebands (MSS4, 0.5 to 0.6 μm; MSS5, 0.6 to 0.7 μm; MSS6, 0.7 to 0.8 μm; MSS7, 0.8 to 1.1 μm) using a hand-held radiometer (Exotech Model 100A, 15° F.O.V.).

Our data base included multitemporal observations from a total of 30 experimental Produra wheat fields (24 in 1977 and 6 in 1978), and 6 fields each of Briggs barley and Anza wheat in 1978. Widely varying yields (103 to 656 g/m^2) were established by two different planting rates in 1977, and differential irrigation regimes during both years.

Midway between emergence and heading in 1977 and 1978, daily measurements of crop spectral reflectances were initiated. Data were obtained between 0920 and 0940 h (MST) on most clear days; and reflectances in each waveband were calculated as ratios of reflected to incident light, as determined by frequent measurements of reflected radiation from a horizontal barium sulfate reflectance standard. The measurements were continued until after canopy senescence in all plots. Final grain yields were determined by hand-harvesting the areas of each plot (ca. 14 m^2) that were regularly viewed with the radiometer.

Work is in progress on developing basic relationships between the spectral reflectance measurements and basic agronomic parameters such as leaf area index (LAI), biomass and phenological stages of growth. To date, two models have been developed which predict final grain yield from the temporal pattern of spectral reflectances.

One such approach to predicting yield is summarized in a manuscript now in press:

Idso, S. B., Pinter, P. J., Jr., Jackson, R. D., and Reginato, R. J.: Estimating of grain yields by remote sensing of crop senescence rates, Remote Sensing of Environment, (In press).

This model uses transformed vegetation index, TVI6, which was calculated from the reflectances of Bands 5 and 6 during the period of canopy senescence

$$TVI\ 6 = \sqrt{\left(\frac{\text{Band 6} - \text{Band 5}}{\text{Band 6} + \text{Band 5}}\right) + 0.5}$$

TVI6 was chosen because it is highly indicative of green leaf area index and is thus responsive to the loss of chlorophyll and the browning of the crop that accompanies senescence. We observed that the highest yielding grain crops were invariably those that senesced most rapidly; and when we used the average daily change in TVI6 as an objective measure of the rate of senescence (Table 1) we found a good correlation with final yield (Fig. 1). Statistical tests showed

no significant difference between results observed for Produra wheat in 1977 or 1978, so we pooled all Produra wheat data and calculated a common regression line which is shown in Fig. 1. Likewise, we found no statistical difference between separate regressions run on both the Anza wheat and Briggs barley data and that of the Produra wheat. Thus, it is possible that a single relationship between senescence rate and final yield may adequately apply to all three crops, although a much wider yield range of Anza and Briggs cultivars is needed to substantiate this hypothesis.

The second yield model uses another vegetation index derived from reflectances in Bands 5 and 7 that is also correlated with the green leaf area index of the canopy. Originally referred to as the Vegetation Index or VI, it has recently been proposed that this index be renamed the Normalized Difference Parameter or ND (Deering, 1978). To avoid any further ambiguity in the use of this generic term we add the subscript "7-5" and define the index as:

$$ND_{7-5} = \left(\frac{\text{Band 7} - \text{Band 5}}{\text{Band 7} + \text{Band 5}}\right)$$

When we plotted ND_{7-5} versus time after planting for each of our experimental plots, a consistent pattern emerged that appeared correlated with final yield. Fig. 2 illustrates this pattern with data from 4 experimental plots in 1977, with a wide range in grain yield. The highest yields occurred in plots where ND_{7-5} was elevated for lengthy periods; conversely, lower yields were associated with a reduction in the index during the period when grain kernels were filling. Such a correlation between ND_{7-5} and yield is theoretically sound since the greater the amount of photosynthetically active tissue (to which ND_{7-5} is very sensitive) following heading, the more photosynthate is available for input into developing kernels. In fact, this approach is similar to that suggested by Watson et al. (1963). They proposed that leaf area duration could be used as a predictor of final yield in wheat. Their LAD was calculated as the integral of green leaf area index with respect to time over the interval from

heading until maturity, thus taking into account not only the maximum LAI but also its persistence during the grain filling period.

We took an approach that was fundamentally similar, but instead of using green LAI in the calculation of LAD we substituted the radiometric index ND_{7-5} minus a baseline value that was equivalent to ND_{7-5} for a dense, totally senescent canopy. Our rationale for subtracting a baseline index value was to minimize the contribution of non-photosynthesizing canopy elements to ND_{7-5}. The baseline was determined empirically for high yielding crops at the end of the season for each year's Produra wheat (in 1977, .422; in 1978, .337), and Briggs barley (0.285), and Anza wheat (0.308). A uniform baseline was then employed for each year and each cultivar. We suspect that variation in the baseline will be minimal from year to year (differences in our data set in 1977 and 1978 were attributed to the use of different radiometers) and between cultivars (as evidenced from our 1978 data). Substitution of ND_{7-5} in lieu of LAI conferred several important advantages. Perhaps the most important is the ease and rapidity with which measurements can be made, eliminating the cumbersome and variable LAI determinations and making it feasible to survey many fields within a very short period of time. In addition, use of a remote, non-destructive technique implies the potential for adapting this approach to remote surveillance systems for predicting yield over broader regions with little or no input of ancillary ground data.

We summed the smoothed daily values of ND_{7-5} minus the baseline for each plot, beginning with the day when 50% of the plants were heading (Feekes scale = 10.5) and continuing until the canopy was totally senescent (i.e., the value of ND_{7-5} dropped below the baseline). Our results are shown in Fig. 3. When the index value was plotted vs. final yield for Produra wheat, we found the data were well described by the exponential relation:

$$y = 67.96e^{0.1081\,x} \quad r = .94 \quad S_{y \cdot x} = 51\ g/m^2$$

where x is the index ND_{7-5} minus the baseline and y is the final yield in g/m^2. Furthermore, data for Briggs barley and Anza wheat also fell within the same range, implying that a similar predictive approach may be applicable to other small grains as well.

The circled data points in Fig. 3 were not included in the regression analysis. They are shown to illustrate that the model does not compensate for reductions in yield late in the season due to extensive bird damage in 3 plots which were originally intended to be our optimum irrigation treatment.

Residual analysis of the data from undamaged plots show that the performance of this model is not affected by planting rate (67 or 137 kg/ha) or total water received (20 to 70 cm). The model performed equally well in predicting 1977 and 1978 yields, even though the 1978 crop was planted 2 weeks later and received three times more rainfall during the winter. Furthermore, our data imply that the fundamental principles involved in this model may be applicable to other grain crops as well.

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2. Deering, D. W. 1978. Rangeland reflectance characteristics measured by aircraft and spacecraft sensors. Ph.D. Dissertation, Texas A&M Univ., College Station Texas, 338 p.

PERSONNEL: P. J. Pinter, Jr., R. D. Jackson, and S. B. Idso.

PART B:

Our canopy temperature experiment this year included a test of the generality of the stress degree day approach to yield production. Temperature data for the three crops, Produra and Anza wheat, and Briggs barley, were obtained daily, as described in previous annual reports. Stress degree days (SDD's) were summed from the time of heading to the initiation of senescence, as determined from daily crop albedo data.

The results, in terms of final grain yield vs. accumulated SDD's, are shown in Fig. 4, where our new data are combined with results from the previous two years at Phoenix. It is seen there that all five of the data sets are overlapping, to the extent that a single relation appears appropriate for all of them. This relation is the solid line running through the midst of the data, as derived by linear regression analysis.

The implications of these results are that the SDD approach to yield estimation is stable (as evidenced by the 3-years' Produra wheat data) and that it is not strongly crop specific (as evidenced by this year's three-variety data). Thus, it continues to meet the demands of long-term testing and acquire characteristics that enhance its utility in a remote sensing context where crop identification is sometimes a problem.

The potential for infrared thermometry in the timely detection of certain biological stresses in plants was investigated. The results, summarized here, are given in detail in a manuscript now in press:

Pinter, P. J., Jr., Stanghellini, M. E., Reginato, R. J., Idso, S. B., Jenkins, A. D., and Jackson, R. D.: Remote detection of biological stresses in plants using infrared thermometry, Science, (In press).

Radiant leaf temperatures of mature, green sugarbeet and cotton plants were measured at midday during the summer near Phoenix and Marana, Arizona. An analysis of the frequency distribution of these temperatures revealed that leaves on diseased plants were usually 3 to 4°C warmer than those on nearby healthy plants (Fig. 5). The temperature differences were attributed to disruption of uptake and/or translocation of water in sugarbeets by the soil-borne fungus *Pythium aphanidermatum* and in two varieties of cotton by the Texas root rot fungus *Phymatotrichum omnivorum*. This characteristic temperature dichotomy between healthy and infected plants persisted under varying soil moisture and atmospheric conditions. Thus, infrared thermometry holds future promise as an advance warning approach capable of

differentiating between physical and biological plant stresses. This is an approach that growers might employ to manage their crops more efficiently and researchers could utilize as a non-destructive diagnostic tool to guide field investigations.

PERSONNEL: S. B. Idso, P. J. Pinter, Jr., R. J. Reginato, and R. D. Jackson

PART C:

A large-scale field experiment was conducted during this past year to test the concept of predicting grain yield utilizing the stress-degree-day concept. The primary thrust of the experiment was to obtain daily ground-based measurements coupled with low-level aircraft data-collecting flights twice weekly, and to determine how well we could predict yield using these different data bases. The following is a chronological review of the experiment as data analyses are incomplete:

The site chosen for this research was a 720-acre field near Dunnigan, 35 miles NW of Davis, California. This site was selected for the following reasons:

1. Terrain typical of the major grain-growing areas.
2. Good farmer cooperation.
3. Close to the University of California, Davis, to facilitate cooperation with University personnel and use of facilities.
4. Close to NASA/Ames Research Center where aircraft flights originate.
5. Climate favorable for dryland grain production.

Sixteen sites were selected within the 720-acre field on which ground measurements were to be made. The 16 sites have various slopes and aspects, with slopes ranging from 0 to 36°. Some of the sites constituted a north-south transect and an east-west transect. Surface temperature measurements were made on bare soils beginning 17 October 1977. The field was planted to barley (var. Briggs) during the period 1 to 7 December 1977. From 8 to 14 December access tubes for the neutron soil moisture meter were installed at all sites and micrometeorological instrumentation was installed on the main site (the area with the N-S and E-W transects).

The weather during the growing season was characterized by above normal rainfall and temperature. Because of these conditions, the barley, for the most part, made good growth. Ground-based measurements were relatively routine, except for a few days when rain prevented measurements, and several aircraft flights had to be cancelled because of inclement weather.

The grower applied 40 pounds per acre of nitrogen fertilizer by aircraft on 01 February 1978, as much of his original fertilizer had been leached from the soil by the heavy rains. During the following two weeks, the barley turned a much darker green, indicating that the fertilizer was being taken up. Even in the low areas that had become waterlogged, the plants responded to the nitrogen. On 20 February 1978, the grower had the field sprayed with a herbicide to kill broadleaf weeds.

In early March heavy rains and high winds caused some of the barley to lodge. Although the plants, mainly on the hills, were laying flat on the ground, the stems were not broken, and growth continued.

Differences in soil moisture between sites (adequate to excess) caused differences in plant growth. Those sites that were well drained made good growth, while those that were waterlogged (poor root aeration) made very poor growth. One site with a south-facing 20° slope, which had adequate moisture, was headed by 27 March 1978, while a level, waterlogged site headed three weeks later. Additionally, those poorly drained areas had more weeds, fewer barley plants, and smaller heads on the plants, than those areas whose soils were well drained.

From October through April, a total of 675 mm (26.56 inches) of rain fell--average rainfall is about 400 mm for that 7-month period. Most of the storms came from the south, accompanied by rather strong winds. Rainfall distribution was quite variable: rainfall on the 20° slope, south-facing site was 565 mm, whereas the 24° slope, north-facing site had 791 mm rain (October 77 through April 78). The two

specific sites mentioned above are the extremes in measured rainfall; all the other sites were somewhere in between. These differences in rainfall resulted in slight differences in available soil moisture later in the growing season.

The aluminum access tubes for soil moisture measurements with the neutron probe were installed at each site to a depth of 180 cm. When a water table formed in the low areas due to the heavy rains, water rose in the tubes, so the depth to the free water surface below ground level was measured. These measurements corresponded quite well with observations of reduced plant growth.

Strong, dry, north winds during the first two weeks in May accelerated the ripening and drying of the barley. By 15 May 1978, the gravimetric water content of the grain was 0.25 to 0.30.

On 22 May 1978, we started hand harvesting the experimental sites within the 720-acre field. The water content of the grain at this time was 0.15. We removed all plants from 20, one-meter squares at each of the sites, counted the number of heads in each square meter, and bagged all samples for further processing. Five consecutive "squares" were taken in each of the four cardinal directions, starting one meter from where we normally stood to take plant temperatures. The 20 samples at each site were, therefore, from the areas where plant temperatures were taken throughout the season. By 26 May, all sites but one were harvested.

Following harvest, all samples (300 of them) were threshed, the number of seeds from each sample was counted, and their weight and water content determined. From these data the following information was obtained:

1. Seed water content
2. Number of heads per square meter
3. Number of seeds per head
4. Number of seeds per square meter
5. Bushel weight of barley
6. Yield

Items 5 and 6 were corrected to a seed water content of 0.125 to allow comparisons of yield between sites.

The highest yielding plot was R4, a 20° slope to the south, with 417.5 gm^{-2}, and the lowest yielding plot was R1, a weed-infested flat area plagued with a high water table, with 104.5 gm^{-2}. The average yield for the 15 sites was 290.7 gm^{-2}. The grower reported a yield of 267.8 gm^{-2}, only 8% lower than our average.

A NASA aircraft made 52 flights over the field during the growing season. Thermal imagery was obtained with a Texas Instruments RS-25 scanner. One striking feature of the thermal imagery is that there were significant temperature differences (4C to 8C) depending on the direction of flight of the aircraft (north-south vs. east-west). The differences are more pronounced where the topography is uneven as compared to level areas.

For mid-May overflights, the warmer surfaces appear to be those which are normal to the line scanner. The afternoon flights took place about one hour past solar noon which resulted in the west- and south-facing slopes being warmer than the east- and north-facing slopes. Indeed, this is what the images show. Whether this phenomenon can be observed under less sunny conditions, or different times of the year, or at various stages of growth of the barley, or on bare soil (wet or dry) remains to be seen as the data analysis is not yet complete. As an example, for a day in mid-May, there was a difference of 10 C between different locations. This points out the necessity of taking many ground-based measurements, in the absense of aircraft support, so that the proper inferences concerning plant stress can be drawn from the data collected.

Aircraft-derived temperature data were averaged for 10, 40, 160, and 640-acre blocks. The mean temperatures of comparable areas for a north-south versus an east-west overflight were essentially the same down to the 10-acre blocks. However, the mean temperatures for 16 May 1978, in the 10-acre blocks ranged from 31.4 C to 36.8 C.

In addition to the various physical parameters being measured daily at each of the 16 sites, insects were collected weekly at each site. We were interested in being able to explain any effects that insect populations found on the barley throughout the growing season might have on crop yield predictions.

Insect collections at each site were taken using 25 sweeps with a sweepnet. The top 20-30 cm of the plants were sampled in this manner. Approximately 12.5 m^2 were sampled for every 25 sweeps taken. Insects were identified while they were in the net, and a killing jar was used to kill insects that were to be pinned and mounted for later identification.

The oat-bird cherry aphid, Rhopalosiphum padi, and the English aphid, Macrosiphum granarium, were the only insect pests that occurred in numbers that were large enough to be considered economically important. Leafhoppers and thrips were collected during the sampling period but only in small numbers. The oat-bird cherry aphid was more prevalent at the beginning of the sampling period than the English grain aphid, but as the growing season progressed, the latter was more abundant. On 18 March 1978, 14,350 oat-bird cherry aphids, compared to 1,668 English grain aphids were collected/ha; a ratio of 8:1. This ratio stayed about the same as both populations of aphids increased until the middle of April. At this time, the populations of oat-bird cherry aphids kept increasing. On the 22nd of April, the English grain aphid was higher by a ratio of 2:1 (19,201:9, 297/ha). By 7 May, when the last sweep samples were taken, there were only 3,436 oat-bird cherry aphids and 1,567 English grain aphids/ha.

The actual numbers of aphids in the barley field were probably higher than what was collected in the sweep samples. Several reasons to support this conclusion are: (1) the sweep samples only covered the top 25 to 50 percent of the barley plants, and (2) at times many aphids were observed on the ground and at the bases of the barley stems. These aphids had probably been dislodged from the upper portions of the plants by wind and/or overcrowding.

The convergent lady beetle, Hippodamia convergens, and syrphid flies, Syrphidae sp., were the only two predators caught in the sweep samples in significant numbers to be considered here as a possible control of the pests that were found on the barley. The numbers of H. convergens caught in the sweep samples was small, but large numbers of adults and nymphs were observed on the ground and on the lower portions of the barley, probably because of the aphids present there. Those aphids would be much more accessible to the H. convergens than the ones on the leaves and stems.

The ratio of pests:predators for the first sweep samples that were taken on 18 March was 24:1, respectively (Fig. 6). The pest population kept increasing for several weeks after this initial sweep sample, while the predator population stayed relatively stable. On 3 April, two weeks after the first sweep sample, the pest:predator ratio was 863:1. From this point on the ratio dropped rapidly for about 3 weeks until it reached a ratio of 16:1 on 22 April. This rapid decrease in the pest:predator ratio was caused by a decreasing number of pests, while at the same time, the predator population was increasing. The ratio stayed the same for several weeks until 7 May, when the ratio dropped to 2:1. This was the last date that sweep samples were taken. This drop in the ratio was probably caused by the senescence of the barley leaves, leaving the pests without green plant material on which to feed. The winged aphids on the plants probably migrated out of the barley field, but the wingless aphids either starved or were consumed by the predators.

Plotting grain yield versus the average number of pests from 25 March (one week before heading) through the soft dough stage (22 April) in Fig. 7 , a definite trend is shown. There is not enough data, however, to establish a cause-effect relationship with regards to numbers of pests and final grain yield.

PERSONNEL: R. J. Reginato, R. S. Seay

Table 1. Agronomic parameters and two indices derived from canopy spectral reflectance, 1976-1977 and 1977-1978 growing seasons in Phoenix, AZ.

	Plot	Number of irrigations	Amt.[1/] water (cm)	Final grain yield (g/m^2)	Average[2/] senescence rate	ND_{7-5}[3/] Index
1976-77 PRODURA WHEAT	1A	4	52.1	455	-0.0172	18.11
	2A	3	40.3	382	-0.0139	14.72
	3A	5	59.3	618	-0.0161	20.65
	4A	1	19.7	147	-0.0087	6.04
	5A	3	42.2	246	-0.0100	11.18
	6AS	4	52.3	506	-0.0141	18.63
	1B	4	52.1	439	-0.0177	17.52
	2B	3	40.3	277	-0.0133	14.65
	3B	5	59.3	401	-0.0162	16.05
	4B	1	19.7	136	-0.0077	4.90
	5B	3	42.2	227	-0.0092	8.24
	6B	4	52.3	450	-0.0145	15.67
	1C	5	62.1	377	-0.0162	15.48
	2C	4	50.4	256	-0.0130	13.23
	3C	6	69.3	494	-0.0164	18.64
	4C	3	39.8	113	-0.0117	7.10
	5C	5	62.4	387	-0.0155	13.69
	6C	5	62.3	453	-0.0155	17.21
	1D	5	62.1	377	-0.0159	17.50
	2D	4	50.4	223	-0.0126	13.73
	3D	6	69.3	508	-0.0157	16.54
	4D	3	39.8	103	-0.0108	7.35
	5D	5	62.4	328	-0.0140	14.82
	6D	5	62.3	459	-0.0150	16.17
1977-78 PRODURA	1A[4/]	6	70.7	125	-0.0108	22.63
	2A	2	39.7	356	-0.0113	17.53
	3A	3	49.7	656	-0.0188	20.64
	4A	3	49.7	544	-0.0122	18.63
	5A	1	29.7	268	-0.0110	13.73
	6A	2	39.7	471	-0.0140	17.31
1977-78 BRIGGS	1B[4/]	6	70.7	429	-0.0172	21.17
	2B	2	39.7	417	-0.0130	18.16
	3B	3	49.7	500	-0.0184	18.18
	4B	3	49.7	383	-0.0133	17.23
	5B	1	29.7	372	-0.0174	15.00
	6B	2	39.7	482	-0.0161	16.49
1977-78 ANZA	1C[4/]	6	70.7	445	-0.0126	22.32
	2C	2	39.7	438	-0.0153	16.64
	3C	3	49.7	543	-0.0165	18.72
	4C	3	49.7	487	-0.0164	19.85
	5C	1	29.7	268	-0.0087	15.20
	6C	2	39.7	436	-0.0150	17.11

1/ Includes applied irrigations plus rainfall during the growing season of 4.7 cm in 1976 and 19.7 cm in 1977-78.

2/ Calculated as the average daily change in TVI6 during the 10-day period when the canopy was senescing most rapidly.

3/ Calculated as the integral (from heading until canopy senescence) of the smoothed daily values of ND_{7-5} less the value of ND_{7-5} for a totally senescent crop.

4/ Yields were severely reduced in these fields due to bird damage.

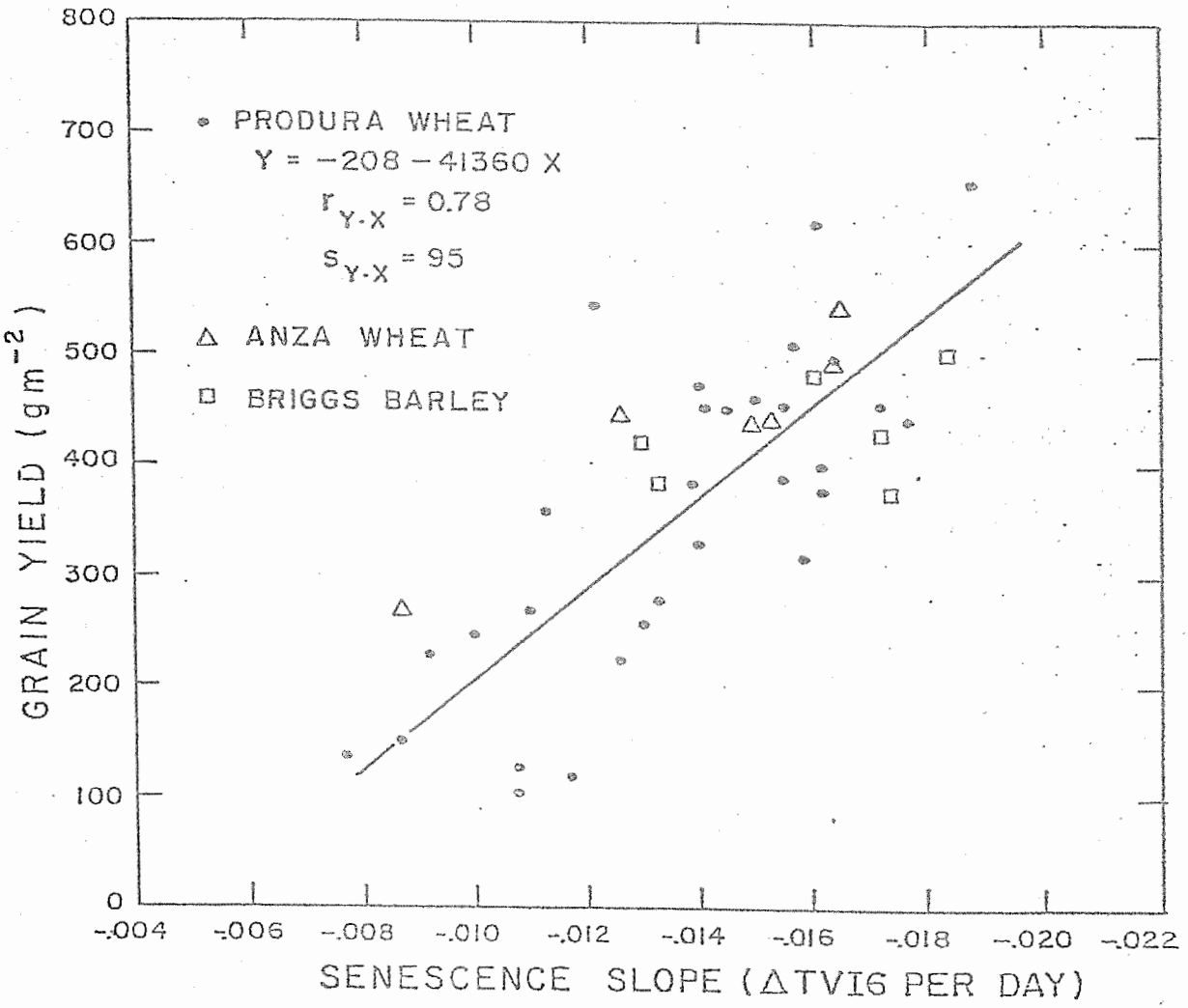

Fig. 1. Final grain yield of Produra wheat, Anza wheat, and Briggs barley vs. senescence rate.

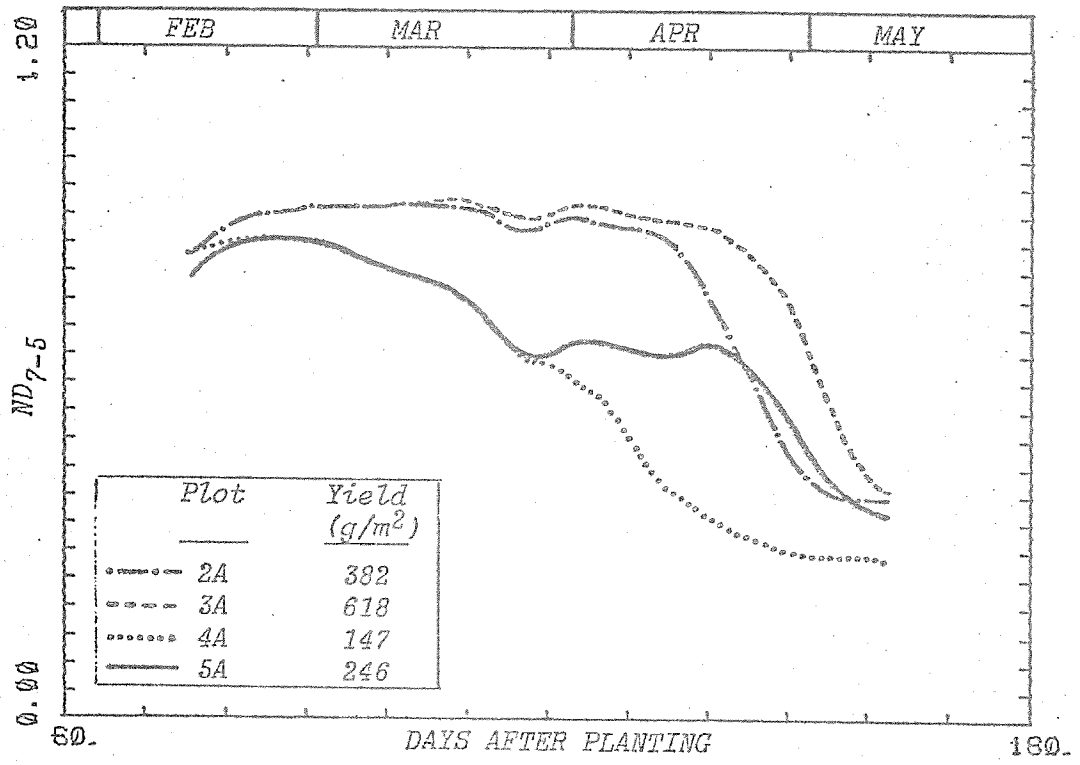

Figure 2. The normalized difference parameter, ND_{7-5}, versus time for 4 Produra wheat fields with widely varying yields in 1977.

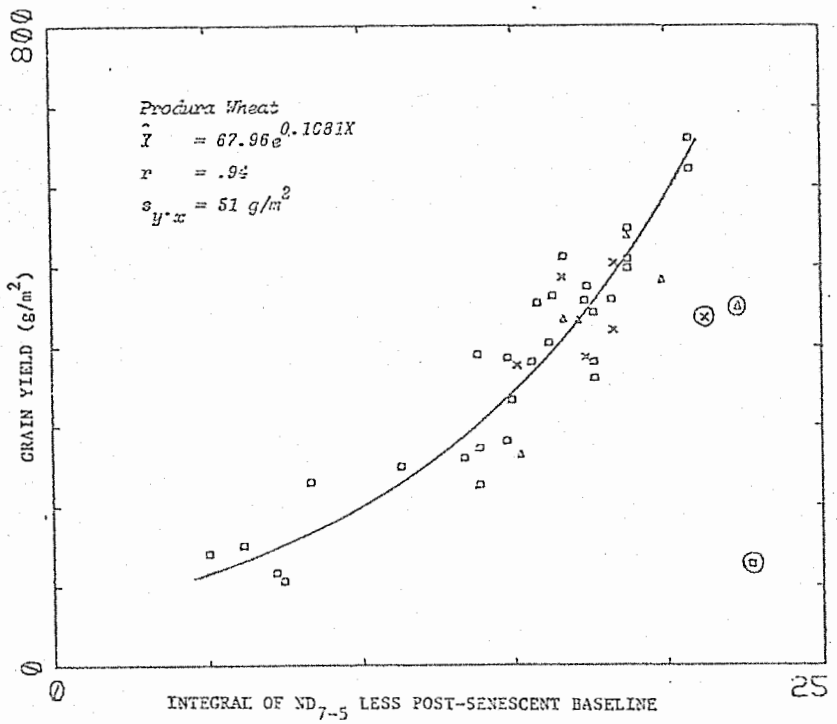

Fig. 3. Final grain yield vs. accumulated daily values, from heading until senescence, of the radiometric index ND_{7-5} minus the value of ND_{7-5} for a dense totally senescent canopy. Circled data points represent 3 fields in which birds damaged up to 88% of the heads. The curvilinear relation was calculated for 29 non-damaged Produra wheat fields. Symbols: Produra (□), Anza wheat (Δ), Briggs barley (X).

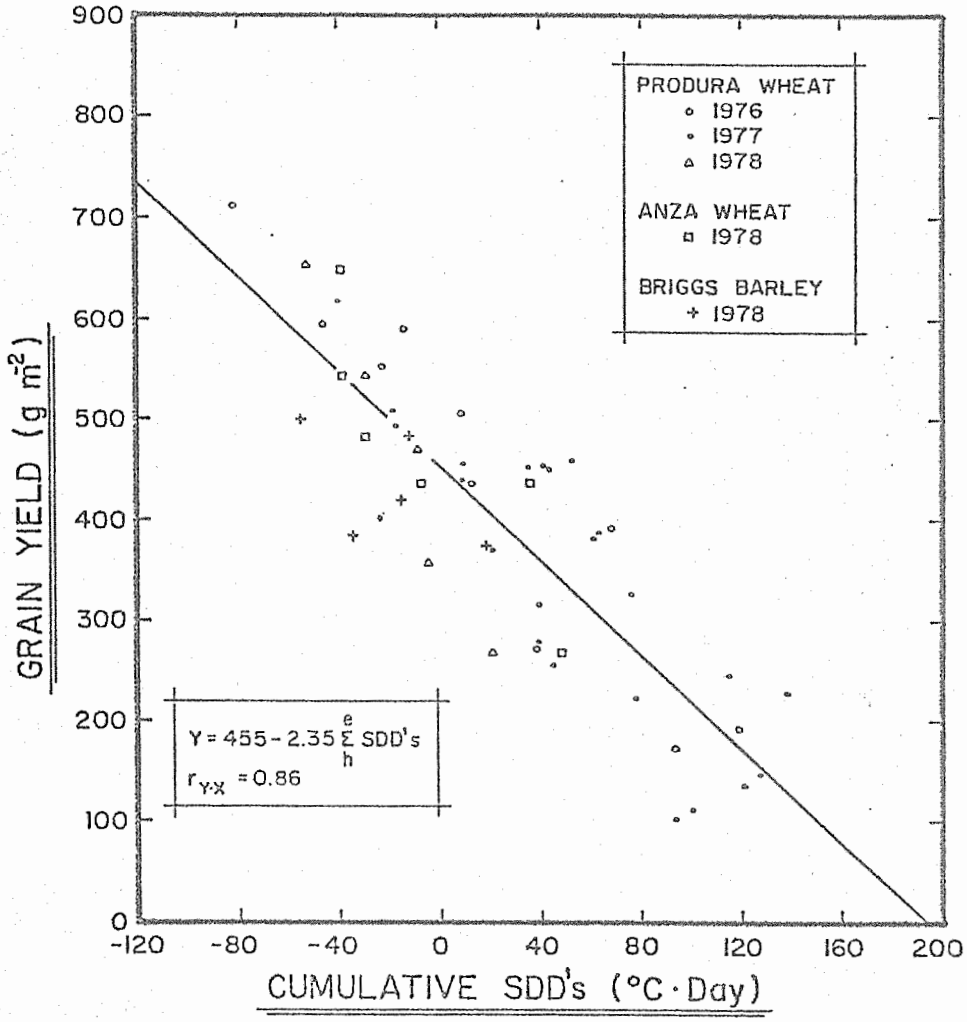

Fig. 4. Grain yield versus cumulative stress degree days for two varieties of wheat and one variety of barley.

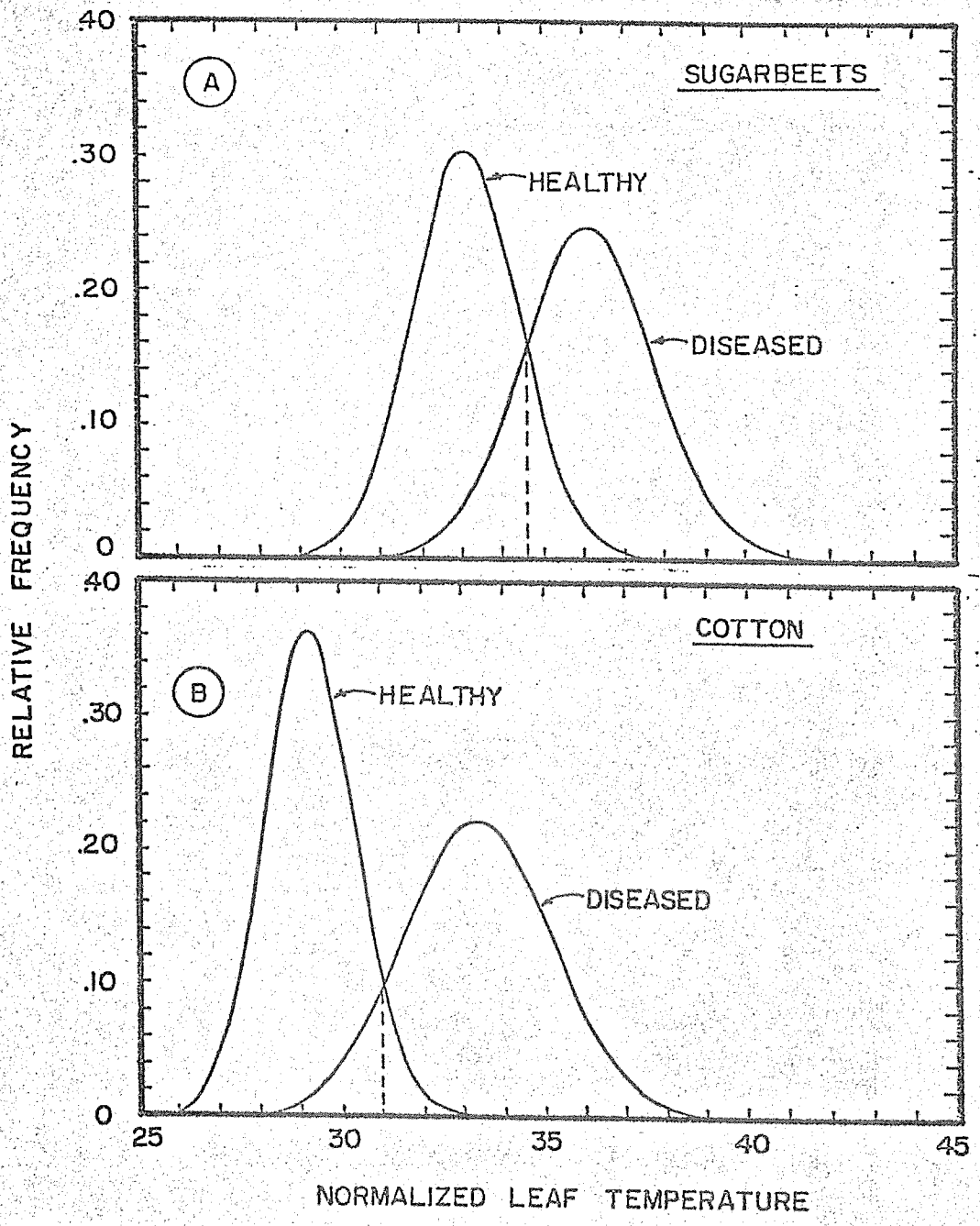

Fig. 5. Gaussian frequency distributions of normalized and combined leaf temperature data for healthy and moderately diseased (A) sugarbeets, and (B) cotton showing the extent of overlap and the temperatures (dashed line) proposed as a discriminator between the two classes.

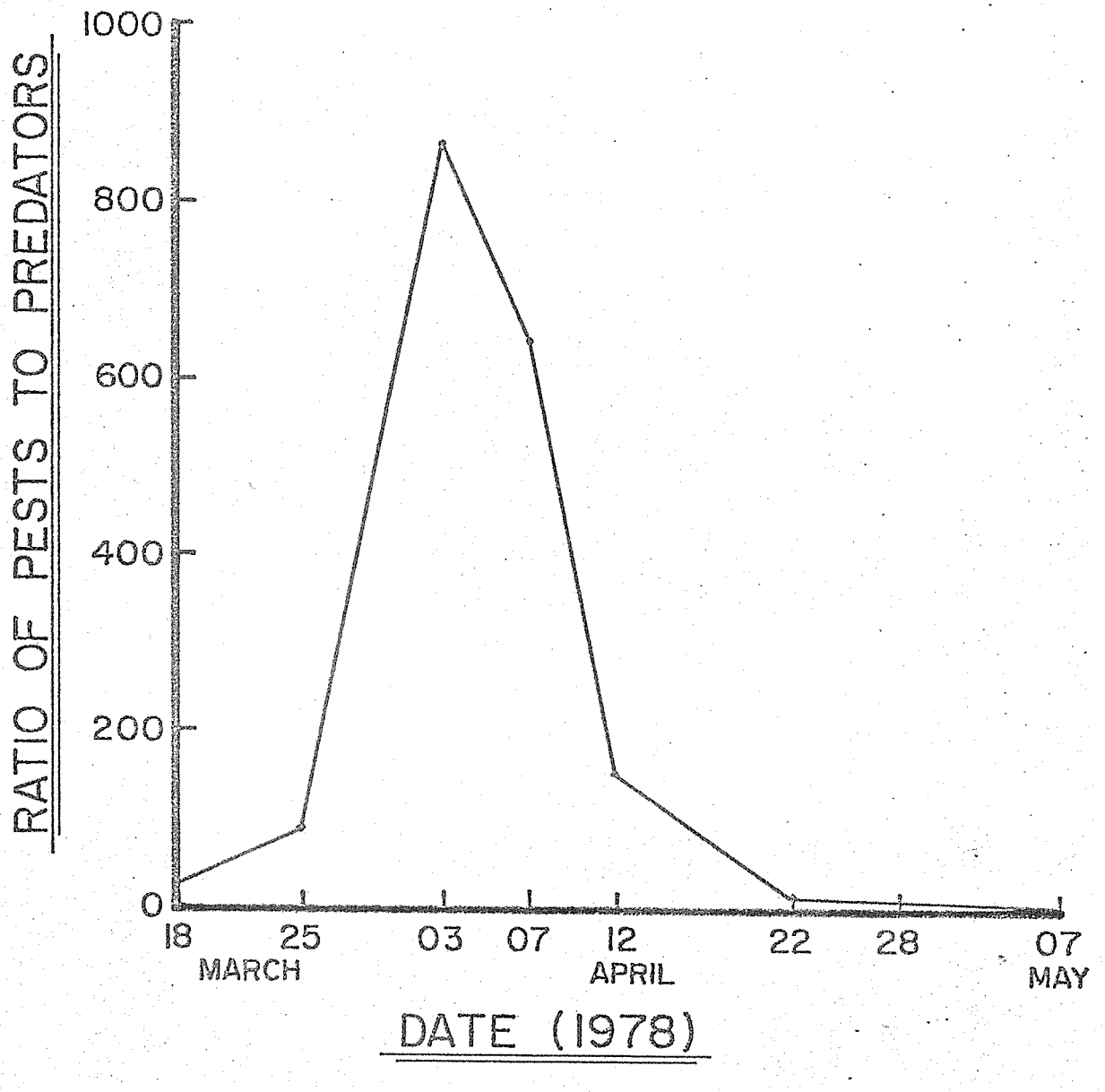

Fig. 6. Ratio of the number of plant pests to predators as a function of time of year for the Dunnigan site.

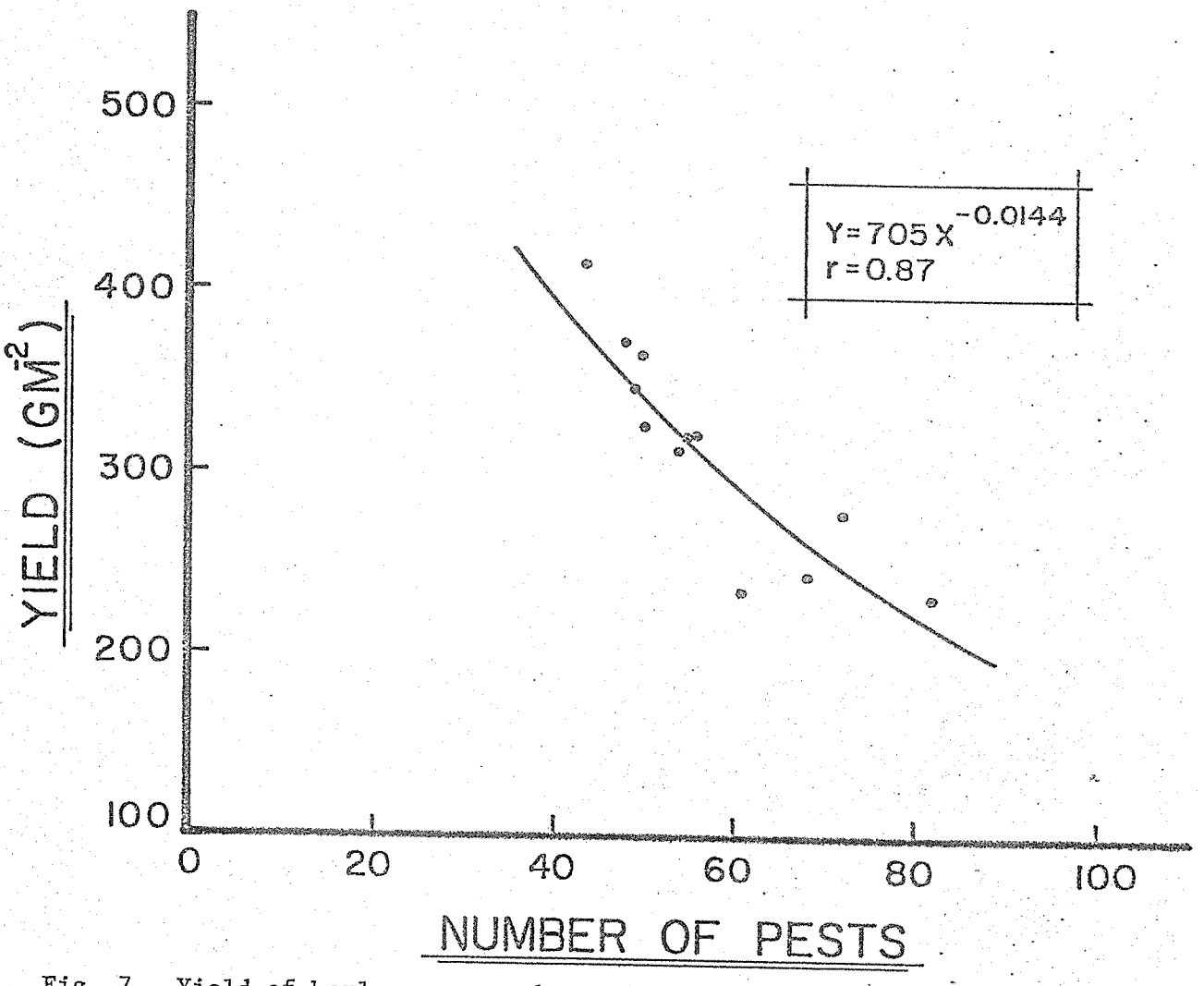

Fig. 7. Yield of barley versus the number of plant pests found at 12 measurement sites at Dunnigan.

TITLE: EFFECTS OF AIRBORNE PARTICULATES ON SOLAR AND THERMAL RADIATION AND THEIR CLIMATOLOGICAL CONSEQUENCES

NRP: 20760 CRIS WORK UNIT: 5510-20760-~~001~~

CODE NO.: USWCL 77-2

Work conducted under the aegis of this outline this year resulted in the publication of one basic research paper, the preparation of a review article, and the initiation of a very detailed experimental program. Each of these efforts is described below.

1. Idso, S. B., and Brazel, A. J. Climatological effects of atmospheric particulate pollution. Nature 274:781-782. 1978.

Atmospheric inversion data and air temperatures from two different altitudes at Phoenix, Arizona were used to demonstrate the significance of the altitudinal distribution of particulate pollution for interactions with solar and thermal radiation. The results of the analysis implied that while the altitudinal location of the particulates did not affect their interaction with solar radiation (which generally results in a cooling trend at the earth's surface), it greatly affected their interaction with thermal radiation (which generally results in a surface warming trend). Specifically, we found that for particulates distributed to several thousand meters' height in summer, the thermal radiation effect was greatly reduced, with a net cooling at the surface. In winter, however, when particulates could only mix to several hundreds of meters, the thermal radiation effect was dominant, with a resultant net warming of the surface. This finding helped to explain why particulate pollution by volcanoes (which often penetrates into the stratosphere) generally leads to surface cooling, while anthropogenic pollution into the surface boundary layer of the atmosphere generally leads to surface warming.

2. Brazel, A. J., and Idso, S. B. Thermal effects of dust on climate. Annals of the Association of American Geographers. In press.

Results of past work on dust particle interactions with solar and thermal radiation were brought together to review the effects of atmospheric pollution on global climate. Two major aspects of the

problem were emphasized: 1) the particulate concentration, and 2) its vertical distribution. Our conclusions were that the initial injection of dust into the atmosphere greatly increases the flux of thermal radiation to the surface, while producing little change in the receipt of solar radiation, for a net warming trend with increasing dust content. At a certain critical concentration, however, the reduction of solar radiation begins to reverse this trend, until at intense duststorm conditions it is overpowering and results in a net cooling at the surface. This is the typical scenario for low-level dust. For aerosols that extend to very great heights, however, the solar radiation interaction is the predominant one, with net cooling practically a universal result.

3. Experiment

A comprehensive experiment was initiated to obtain direct experimental evidence for the "thermal blanketing" effect of atmospheric dust, which is basically as described above. It consists of obtaining measurements of incoming global, normal-incidence, and diffuse solar radiation, incoming thermal radiation in the 10.5-12.5 μm and 8-14 μm wavebands, as well as the full thermal spectrum, and auxiliary measurements of air temperature, vapor pressure, and dust concentration.

The instruments are all located on the laboratory roof and have been in continuous operation since early June 1978, recording data at half-hourly intervals. Considerable analysis of the information obtained has indicated a wealth of important results will be born of the experiment. In particular, the data have already verified the hypothesis that the major variability of atmospheric emissivity is due to the varying concentration of a dimeric species of water vapor. New and improved equations have consequently been derived for total effective atmospheric emittance, as well as for the individual 10.5-12.5 μm and 8-14 μm wavebands.

The partial "closing" of the so-called atmospheric window by the thermal blanketing effect of dust has been successfully directly measured for the first time, and has verified the hypotheses described

in this year's two publications. This result has also allowed a determination of the actual temperature response of the atmosphere to dust variability to be made. An independent determination of the surface atmosphere's response to water vapor variations yielded an essentially identical result. These two observations thus led to a numerical evaluation of the effects of carbon dioxide on climate. Since the manuscripts describing these findings have not yet been completed, however, a full report will not be made until next year.

PERSONNEL: Sherwood B. Idso and Anthony J. Brazel (cooperator from Geography Department, Arizona State University).

TITLE: CARBON DIOXIDE TREATMENT OF SOILS TO IMPROVE PHOTOSYNTHETIC EFFICIENCY OF CROPS AND NUTRIENT AVAILABILITY

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: USWCL 78-2

INTRODUCTION:

Laboratory and greenhouse studies have shown that plant yield can be improved by CO_2 enrichment of the atmosphere surrounding the leaf. Limited studies in the field have also shown this to be valid, but the method of aerial CO_2 application to plants is impractical for economical crop production. Instead of increasing the CO_2 content in the air, CO_2 enrichment via the root environment has been shown to improve crop yield. Whether such favorable results are caused by CO_2 uptake by roots to increase photosynthesis or other side benefits, such as improved soil-root environment for nutrient uptake, has not been clearly shown. The application of CO_2-treated water subsurfacely using existing buried trickle irrigation tubing appears to be a practical and economical means for getting the CO_2 to the plants. Thus, trickle systems presently in use could reap additional benefits.

The initial phase of the study included the development of ways to incorporate CO_2 injection with the subsurface trickle system and to work with several crops to find out the effect of such subsurfacely applied CO_2 treatment.

Carbon dioxide injection system. Several methods for introducing gaseous CO_2 into the irrigation water and then into the trickle lines were tried. For small treatment areas, the most practical method found for field use was the commercially available carbonator. The system has a built-in diffuser that breaks the entering CO_2 gas into small bubbles for increasing contact with the water so that CO_2 dissolution in water can be hastened. It also has a pump which can increase or maintain the pressure on the outlet side of the carbonator. A schematic diagram for the CO_2-water injection system used in the experiments is presented in Figure 1. Several safety features were included in the carbonation system design.

Supply water was passed through an anti-siphon vacuum breaker valve to prevent any backing of water to the supply source when the system was turned off. The pressure switch (P/S) prevented the system from turning on if the water supply pressure was too low. This prevented the pump motor in the carbonator from running dry and overheating. The time clock was used to activate the solenoid valves (S/V) on the water line and the gas supply sides. A gas flow meter was used to measure the rate of CO_2 injection. The check valve (C/V) prevented any water from backing into the gas lines should there be a drop in gas pressure or sudden surges in water pressure.

The system could also be operated without the carbonator, if needed, by disconnecting the electrical leads to the carbonator and gas solenoid valve, and closing valves 3 and 5 and opening valve 4. The normal operational mode was to have valve 4 closed and valve 5 open. Valve 3 operated in the by-pass mode. Part of the supply water went through the carbonator to be saturated with CO_2 and the remaining portion mixed with carbonated water and led into the trickle lines through valve 5. The pH of the raw water was decreased approximately 2 pH units, from 7.2 to 5.2 in the mixing process.

With the CO_2-air mixture supply, compressed air was combined with CO_2 from the liquified CO_2 tank source (Fig. 2). A concentration of approximately 5% CO_2 by volume was achieved by adjusting the control valves and monitoring the flow rates of CO_2 and air going into the mixing tank. The CO_2-air mixture was then lead to the trickle lines.

CARBON DIOXIDE TREATMENT

A. Wheat.

Procedure: A wheat crop (Produra) was established on a 7 x 19 m plot on 18 December 1977, and harvested 16 May 1978. Plant rows were spaced 17.8 cm apart with double-tube trickle irrigation tubing buried 20.3 cm deep between the rows. Eight plant rows were used per replicate with the two innermost rows sampled for yield measurements. Planting rate was 2×10^6 plants per hectare. Nitrogen as ammonium nitrate and urea was applied at a rate of 190 kg/ha, and phosphorus as phosphoric acid at a rate of 67 kg/ha. The nitrogen

was added in four increments and phosphorus in two with the trickle system through the early stages of the wheat development.

The rate of CO_2 application for the CO_2-water system was 1.9 $g/m^2/hr$ with the CO_2-water mixture applied at the time of irrigation. carbon dioxide for the CO_2-air treatment was 4.4 $g/m^2/hr$. For this treatment the gas mixture was applied daily during the daylight hours of 1000 to 1500, starting in February and extending to 0900 to 1700 hours in May.

Gas sampling probes were installed in the plots at various depths to measure CO_2 concentration in the soil profile. These were put in after the experiments were started since the necessary equipment was not available at planting time. Hypodermic syringes were used to sample 2 to 5 cm^3 of the soil atmosphere, and the CO_2 content was determined on the gas chromatograph.

Plants were irrigated following the consumptive use curve. Heavy rains in latter December and continuing through January decreased the need for water application, and with the CO_2-water treatments would have meant less CO_2 application than initially anticipated. Thus, the experiment was modified to include the CO_2-air treatment.

RESULTS AND DISCUSSION:

The CO_2-water and CO_2-air treated plots out-yielded the check plot (Table 1). These yields were approximately 20% greater than the check. Their straw weight was significantly higher and the number of heads/m^2 was also greater than the check plots. No significance was obtained on the individual kernel weight. The carbon dioxide concentrations in the profile were increased by both the CO_2-water and CO_2-air treatments (Table 2). Limited analytical equipment prevented more detailed monitoring of the CO_2 status. Under normal conditions, CO_2 concentrations were in the order of 0.2 to 0.5% from 2.5 to 10 cm depth, and increased to 1.00 and higher from 20 to 60 cm.

The 7.2 pH of the irrigation water was reduced to 5.3 with the CO_2 treatment. Soil pH measured on moist soil in the field was 8.0 compared to 6.4 for the CO_2-water treated soil.

B. Cabbage.

Procedure: Cabbage was seeded in double-row geometry on 100-cm wide beds. Double-wall trickle tubing was previously buried 15 cm below the soil surface. The CO_2-water and checks were randomly replicated 4 times on the 1 x 18 m plots. The seeds were planted on 26 September 1977, and harvesting started 4 January 1978, and continued to 21 February 1978. Soil gas sampling probes were installed at various depths to 80 cm along the plant row in October. Irrigation scheduling followed the consumptive use curve. Heavy rains in December reduced trickle irrigation application of carbonated water. Nitrogen, as urea, was applied at a rate of 140 kg/ha in three increments with the trickle irrigation system.

The CO_2-treated water was prepared in a manner similar to the preceeding wheat experiment. Carbon dioxide was applied at the rate of 4.1 $g/m^2/hr$ during the irrigation period.

RESULTS AND DISCUSSION:

The cabbage yield for the different treatments is compared in Table 3. No significant yield difference was obtained between the two treatments.

Carbonation reduced the pH of water from 7.7 to 5.2, and the pH of the soil from 8.0 to 6.4. Analyses of leaf samples has not been completed.

C. Potato.

Procedure: Potato (Kennebac) was planted on 23 May 1978, on the same plot as the cabbage experiment. Replication was increased from four to eight. The bed width was set at 86.4 cm, and plant spacing in the row was 17.8 cm, with seed planted at a depth of 17.8 cm. Double-wall trickling irrigation lines were buried 7.6 cm deep and approximately 10 cm laterally from the seed piece. Irrigation quantities with carbonated water followed the consumptive use curve. Carbon dioxide was applied at 4.2 $g/m^2/hr$. Nitrogen (168 kg/ha) and phosphorus (224 kg/ha) were applied in five increments, including preplant fertilization.

RESULTS AND DISCUSSION:

The plants in the CO_2-treated plots appeared to be greener with more growth than those in the check plots. The differences, however, became obliterated as the plants matured. Yield comparisons are made in Table 4. The CO_2-treated plots had approximately 10% greater potato yield than the check, but this was not statistically significant. The leaf-to-tuber ratio was significantly smaller in the CO_2-treatment (1.79) than in the check (2.74).

D. Cantaloupe

Procedure: Cantaloupe for fall production was seeded on 1 August 1978, on a 1.5 m wide by 17 m long plot with 8 randomized replicates per treatment. The plots were previously planted to potato. The double-tube trickle irrigation tubing was buried 20-cm deep in the middle of the bed prior to planting. Plants were thinned to one plant/30.5 cm on 29 August. Application rates of nitrogen and phosphorus fertilization followed commercial practices by growers in this area.

The consumptive use curve was utilized for determining irrigation quantities. Water use by the crop was also followed by the neutron moisture measuring technique. Carbon dioxide was applied with the irrigation water at the rate of 8 $g/m^2/hr$. Soil atmosphere sampling probes were installed at depths of 2.5, 5, 10, 20, 40, and 60 cm. Gas samples were analyzed for CO_2 with the gas chromatograph.

Fruit harvesting began on 13 October and continued to 13 November. There were 9 pickings during this period with two- to three-day intervals between harvest. The number of fruit per plot, weight of the different sizes and fruit quality were measured during and immediately following the harvesting process.

RESULTS AND DISCUSSION:

At the early stages of growth, the plants in the CO_2-treated plots appeared more luxuriant in growth compared to the untreated plots. The difference, however, was hard to discern after the vines fully covered the bare plots.

The pH of the irrigation water was decreased from 6.9 to 5.2 with the CO_2 treatment. Soil pH was also lowered from 7.7 to 6.2 in the moist soil around the trickle tube discharge.

Powdery mildew was observed in all plots during the latter part of September and chemical spray treatment to control the infestation was started. Spraying was timed so it would not interfere with the harvesting of the crop.

Marketable cantaloupe yield was 60.0 kg/plot (241 crates/acre) for the check and 70.1 kg/plot (283 crates/acre) for the CO_2-treated plots. The 17% increase in yield was not significant, however.

Various aspects of fruit quality are compared in Table 5. Overall sugar content average for the three sampling dates was 9.3 and 9.7 for the check and CO_2 treatments, respectively. The difference is statistically significant only at the 20% level. The other subjective tests based on visual observations did not indicate much difference in quality between the CO_2-treated and untreated plots.

The high variability encountered in this, as well as other studies may be caused by non-uniformity in the trickle tubing used for irrigation and CO_2 application. Disease was also a problem in the cantaloupe work. The growing season was especially wet for all crops, so the full potential of the CO_2 treatment may not have been achieved. Different levels of CO_2 could not be used because of lack of equipment and plot area. The study was primarily exploratory in nature to see whether the field equipment will work in field-type situations. More extensive measurement in regard to plant growth and CO_2 flux and CO_2 distribution should add to the understanding of the basics of the CO_2 treatment.

The carbon dioxide levels in the soil profile followed a regular pattern before and after irrigation with the non-carbonated water (Table 6). Gas samples were taken before, during, and after an irrigation cycle. At 2.5-cm depth, the soil CO_2 content is approximately ten times the ambient atmospheric concentration, and at 20 cm (8 in.) it is higher by approximately thirty times. Whether the CO_2 concentration and gradient present in the soil can adequately supply optimum

CO_2 levels for maximum photosynthesis in unknown. By approximation using the flux relation $f = -k(dc/dx)$, the CO_2 flux from 20-cm depth would be 1.4 g of $CO_2/m^2/hr$. This is the value under ideal conditions. Values in the literature range from 0.2 to 0.5 g of $CO_2/m^2/hr$.

The CO_2-water treatment did increase the CO_2 concentration in the soil atmosphere, but this is evident only while the carbonated water was being put subsurfacely to the plots (Table 7). The check CO_2 values are the averages from the preceeding table. The two different sites (A and B) gave different CO_2 levels. The paired A and B CO_2 analyses for a given treatment period can be compared with the untreated by using the same treatment days. For example, in the 7-hour treatment run of 6 September, the CO_2 level had increased in CO_2-water concentration as indicated in Table 7, whereas very little CO_2 change had occurred in the check of Table 6 for the same day. By 8 September, the CO_2 levels in the profile for the CO_2-treatment were nearly those of the untreated plots. Carbon dioxide application by the CO_2-water combination is limited to the irrigation period. Thus, if water application is decreased because of rain, as was the case for this year's experiment, less CO_2 would be applied.

A salient requirement in this type of study is the need for a uniform application trickle system. This is important not only from the standpoint of water application, but for fertilizer and CO_2 application as well.

SUMMARY:

A carbon dioxide-water mixture was applied with a subsurface trickle irrigation system for the purpose of increasing CO_2 uptake by the plants through the root system. Results for potato, cabbage, and cantaloupes were too variable to achieve statistical significance, but the trend was for increased yield in the potato and cantaloupes with no difference in cabbage. Wheat yield showed a significant increase, with the results for the CO_2-water treatment being similar to the CO_2-air treatment. The quantity of CO_2 applied in the CO_2-water treatment was limited by the amount of irrigation water used.

The combination of CO_2-water or CO_2-air applications may be used in increase CO_2 application rates.

An effort should be made to see whether the naturally occurring high concentrations of CO_2 in the soil atmosphere could be used to advantage for increasing the CO_2 flux to the leaf by moving the gas upwards with subsurface trickle irrigation systems.

PERSONNEL: Francis S. Nakayama, Barbara A. Rasnick, Dale A. Bucks

Table 1. Comparison of wheat yield for the various CO_2 treatments.

Treatment	Wheat Yield [Tons (metric)/ha]			
	Grain	Straw	Heads / m^2	Individual kernel wt. (mg.)
Check	6.92	5.83	3.89	53.2
Air-CO_2	8.51*	8.98*	5.29*	49.0
H_2O-CO_2	8.23*	7.26*	4.60*	50.2

* Significant at the 1% level.

Table 2. Carbon dioxide concentration in CO_2-water treated plot (9 May 1978).

	CO_2 Concentration (%) (Time)					
Depth (cm)	0800	1000	1200	1400	1600*	Check
2.5	0.22	1.70	2.24	2.45	1.76	0.19
5.0	0.36	1.27	1.90	2.28	2.04	0.28
10.0	0.52	1.12	1.80	2.32	2.49	0.61
20.0	--	1.66	2.28	3.05	3.44	1.00
40.0	2.45	2.46	2.32	2.35	2.73	1.32
60.0	2.59	2.75	2.67	2.72	2.75	1.14

* Analyses for the CO_2-air treatment; air = 0.06% CO_2.

Table 3. Comparison of cabbage yields between the CO_2-treated and untreated systems.

	Cabbage Yield [Tons (metric)/ha]			
Treatment	Marketable yield	Culls	Total	Individual heads (g/head)
H_2O-only	55.5	6.5	62.0	962
H_2O-CO_2	53.0	5.7	58.7	917

Table 4. Comparison of potato yields between the CO_2-treated and untreated irrigation systems.

	Potato Yield [Tons (metric)/ha]			
Treatment	Jumbo, #1, #2	PeeWee	Culls	Total
H_2O-only	20.4	0.89	1.82	22.7
H_2O-CO_2	22.7	1.02	1.76	25.4

Table 5. Cantaloupe fruit quality for fall harvest.

Date	Treat-ment	Genl. cond. 1/	Net 1/	Outside color 1/	Inside color 1/	Dry-ness 1/	Cavity length (cm)	Cavity width (cm)	Flesh firm-ness 1/	Sugar (%) 2/
10/23	Check	4.0	4.7	4.6	5.1	3.3	8.5	5.2	4.7	8.7
	CO_2	4.5	5.4	5.2	5.4	3.7	8.4	5.3	5.3	8.9
10/26	Check	4.9	5.6	5.3	5.5	3.6	9.0	5.4	5.7	9.8
	CO_2	4.8	5.1	5.2	4.6	3.0	8.4	5.1	5.1	10.5
10/30	Check	4.0	4.7	4.6	5.1	3.3	8.5	5.2	4.7	9.4
	CO_2	4.5	5.4	5.2	5.4	3.7	8.5	5.3	5.3	9.7

1/ Visual evaluation, rated on scale from 1 through 9, with 9 the most desirable.

2/ Measured with sugar refractometer.

Table 6. Carbon dioxide concentration (%) in soil profile, following trickle irrigation (mean of two sampling sites).

Depth (cm)	Dates									
	06 Sept.	06 Sept. (7 hr.)	07 Sept.	08 Sept.	15 Sept.	15 Sept. (2.5 hr)	22 Sept.	22 Sept. (1 hr.)	29 Sept.	29 Sept. (2 hr.)
2.5	0.20	0.38	0.34	0.26	0.23	0.25	0.54	0.57	0.36	0.37
5.0	0.30	0.44	0.42	0.32	0.32	0.32	0.68	0.66	0.45	0.38
10.0	0.50	0.56	0.63	0.47	0.45	0.51	1.06	1.10	0.65	0.70
20.0	0.80	0.76	0.88	0.72	0.94	0.63	1.78	1.78	1.14	1.04
40.0	1.64	0.93	1.36	1.25	0.84	1.26	1.44	1.54	1.34	1.38
60.0	--	--	--	--	--	--	--	--	1.16	1.26

Depth (cm)	Dates								
	06 Oct.	06 Oct. (1 hr.)	13 Oct.	13 Oct. (1 hr.)	20 Oct.	20 Oct. (0.5 hr)	27 Oct.	27 Oct. (2 hr.)	Overall average
2.5	0.34	0.33	0.28	0.35	0.32	0.32	0.14	0.29	0.33
5.0	0.42	0.37	0.34	0.40	0.37	0.38	0.18	0.34	0.40
10.0	0.62	0.58	0.46	0.53	0.50	0.55	0.25	0.35	0.55
20.0	1.22	1.19	0.91	0.95	0.86	0.82	0.47	0.48	0.97
40.0	1.53	1.73	1.28	1.26	1.17	1.00	0.92	0.84	1.26
60.0	1.19	1.27	1.15	1.18	1.08	1.16	0.86	0.88	1.12

Table 7. Carbon dioxide concentration (%) after treatment with CO_2-water of various durations.

Depth (cm)	Check (0 hr.)	20 Oct. (0.5 hr.) A	20 Oct. (0.5 hr.) B	22 Sept. (1 hr.) A	22 Sept. (1 hr.) B	06 Oct. (1 hr.) A	06 Oct. (1 hr.) B	13 Oct. (1 hr.) A	13 Oct. (1 hr.) B	29 Sept. (2 hr.) A	29 Sept. (2 hr.) B	27 Oct. (2 hr.) A	27 Oct. (2 hr.) B
2.5	0.33	0.45	0.51	0.70	0.27	0.74	0.86	0.91	1.94	0.84	0.51	0.69	3.44
5.0	0.40	0.73	2.57	1.06	0.21	1.50	4.05	2.78	3.83	>5	0.49	1.46	>5
10.0	0.58	0.83	0.96	1.33	0.71	2.47	1.84	2.78	2.57	4.83	1.59	0.78	1.97
20.0	0.97	1.19	1.63	1.81	1.33	2.33	2.74	2.93	>5	2.31	3.81	0.77	4.69
40.0	1.26	1.13	1.15	1.52	1.21	1.61	1.78	1.29	1.25	1.49	1.29	0.87	0.78
60.0	1.12	1.07	1.19	--	--	1.44	1.41	1.29	1.34	1.37	1.20	0.70	1.00

(Continued)		15 Sept. (2.5 hr.) A	15 Sept. (2.5 hr.) B	06 Sept. (7 hr.) A	06 Sept. (7 hr.) B
2.5	0.33	1.26	0.26	2.59	0.40
5.0	0.40	>5	0.32	>5	0.43
10.0	0.58	>5	0.53	>5	1.20
20.0	0.97	1.28	0.19	3.47	2.78
40.0	1.26	1.28	1.04	0.97	0.64
60.0	1.12	--	--	--	--

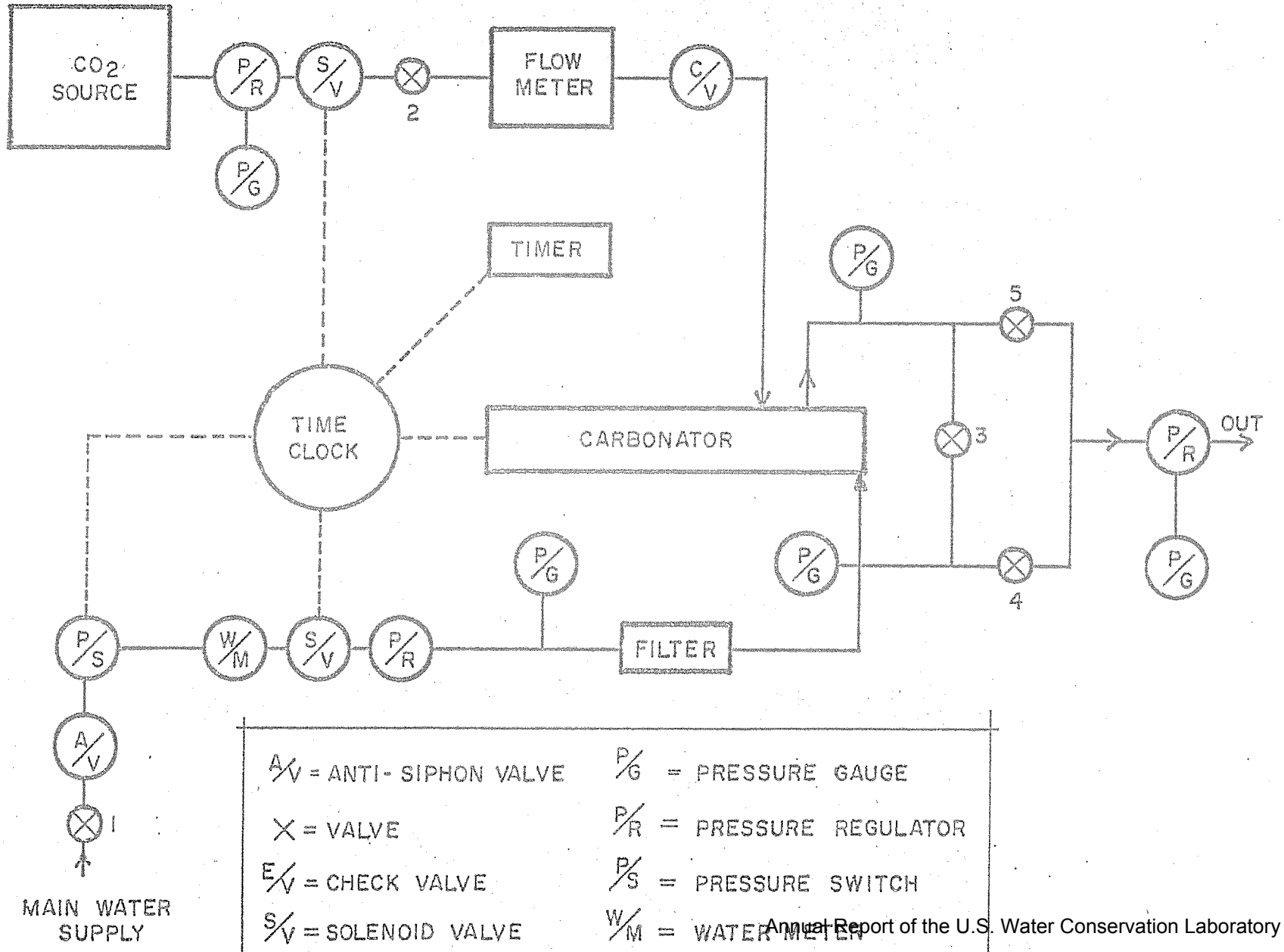

Figure 1. Equipment for producing CO_2-water mixture for trickle irrigation system.

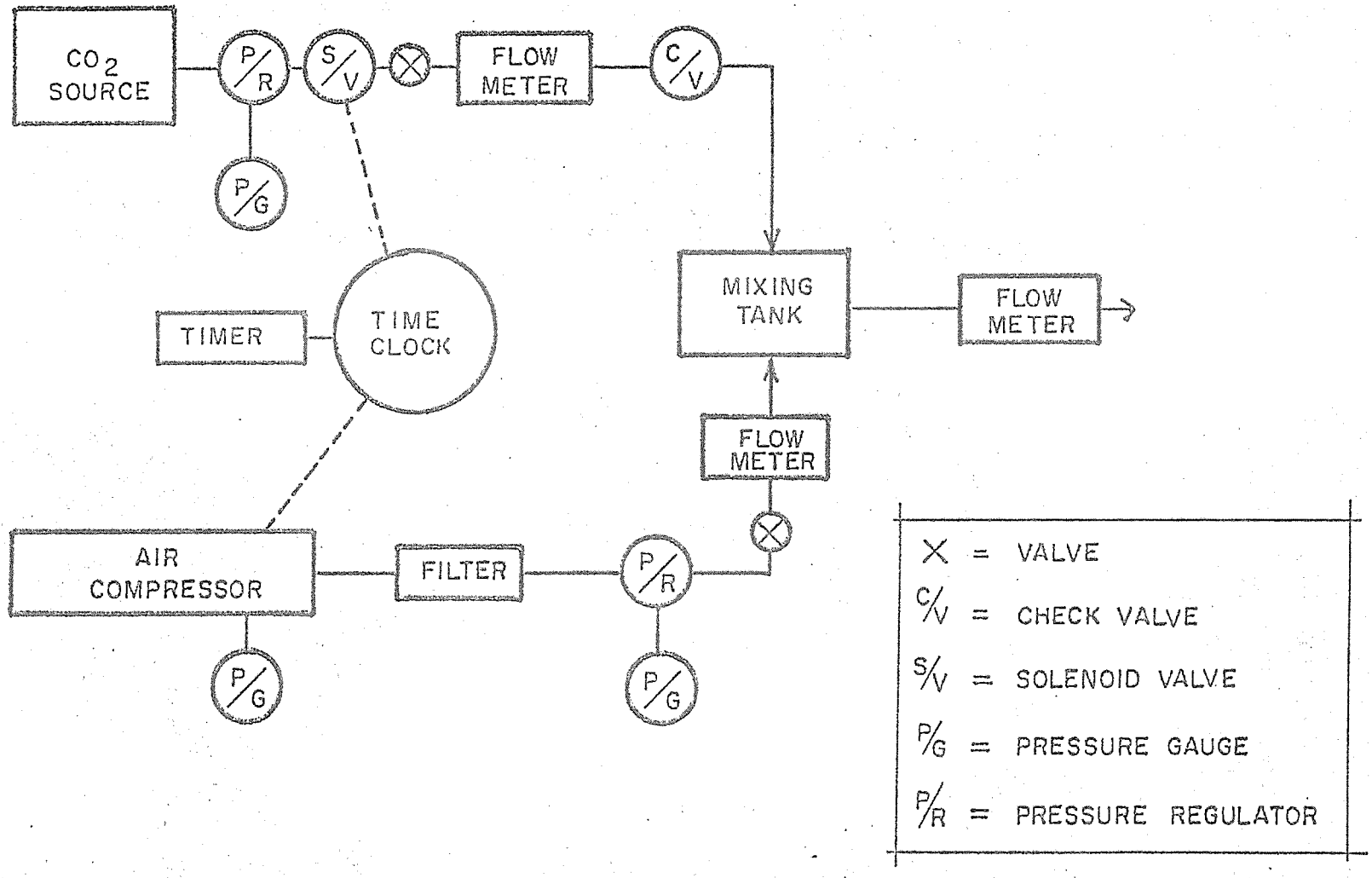

Figure 2. Carbon dioxide-air gas mixing system for use in trickle irrigating tubing.

TITLE: EVALUATION OF CO_2-ENRICHED, UNVENTILATED, SOLAR-HEATED GREENHOUSES

NRP: 20760 CRIS WORK UNIT: 5510-20760-001

CODE NO.: USWCL 78-4

INTRODUCTION:

This project is a continuation of the work described in earlier annual reports under the project title, "Temperature control of CO_2-fertilized, sealed greenhouses." The change was made to make the outline somewhat more general and to conform to the new format with outside peer review of the project outline.

REVIEW OF MANUSCRIPTS:

A major objective of this project is to evaluate the crop yields attainable with CO_2 enrichment in unventilated greenhouses. The first results from the spring 1977 and the winter 1977-78 crops of "tropic" tomatoes have been described in two manuscripts, "CO_2 enrichment of tomatoes in unventilated greenhouses in an arid climate" (Kimball and Mitchell, 1979b) and "Tomato yields from CO_2 enrichment of unventilated and conventionally ventilated greenhouses" (Kimball and Mitchell, 1979d). For the spring 1977 crop, the conventionally ventilated control house at ambient CO_2 had a high yield of 8.58 kg/plant. Unventilated houses enriched with 650 and 1000 μℓ/ℓ CO_2 during the daytime had 17 and 48% greater yields than the control. An unventilated, unenriched house suffered a 13% yield decrease attributable to depletion of CO_2 or possible detrimental effects of higher humidity.

Before the winter 1977-78 crops, the houses were subdivided into two beds; one bed received the standard nutrient level used in the first experiment, and the other received a 50% more concentrated solution. At the standard nutrient level, the marketable yield of tomatoes was 8.48 kg/plant in the conventionally ventilated control house at ambient CO_2. Unventilated houses had yields 64 and 63% greater at 1000 and 1350 μℓ/ℓ CO_2, respectively, and a ventilated house at 1000 μℓ/ℓ CO_2 had a yield 8% greater. At the high nutrient level, the control house yielded 9.70 kg/plant. The other yields were 35, 37, and 10% greater in the 1000 and 1350 μℓ/ℓ CO_2 unventilated houses, and the 1000 μℓ/ℓ ventilated house, respectively.

During January and February 1978, the effects of the treatments on tomato taste were evaluated using taste panels. The results are described in "Effects of CO_2 enrichment, ventilation, and nutrient concentration on the taste of tomatoes" (Kimball and Mitchell 1979c). Four 15-member untrained taste panels scored individual tomatoes from each of the eight treatments, plus additional field-grown and hydroponic greenhouse tomatoes from a market, for color or general appearance, texture, aroma, overall consumer acceptability, and rank. The field tomatoes scored significantly (at 5%) lower in all six categories. The hydroponic tomatoes had better color than some of the unventilated treatments, but generally were not significantly different from the experimental tomatoes. There were no significant effects of CO_2 concentration for any of the scoring categories. Lack of ventilation caused a small but statistically significant impairment of color, flavor, acceptability, and rank, while higher nutrient concentration caused a small but significant improvement of these same categories.

During 1978, an improved psychrometer was developed as described in "An accurate, low-maintenance psychrometer" (Kimball and Mitchell 1979a). The psychrometer features a force-feed wicking system to prevent drying of the wick. A miniature pump recirculates the water over an inner wet bulb radiation shield. The water cools to wet bulb temperature, thereby eliminating the radiation error on the wet bulb and also the conduction error of heat flow in the wick. The design also features quick assembly for easy servicing of the wick. The psychrometer will be used to measure accurately the wet bulb of the arid outdoors and also in a differential mode to measure the increase in enthalpy of the air passing through a greenhouse.

METHODS:

Greenhouse maintenance in 1978. During the spring of 1978, little or no water was draining into the irrigation drainage sumps in greenhouse #2, the control house. Therefore, after the crop had been removed from the greenhouse, drainage tests were performed in all four houses by flooding the beds on 12 June 1978 and observing

the decline of water level in the drainage sumps (sump pumps off). By 19 June, the water levels had dropped .75 and 1.5; 6.5 and 5.5; 1.25 and .75; and 1.25 and 1.0 for the "low" and "high" beds in greenhouses 1, 2, 3, and 4, respectively. Therefore, during the week of 20 June, the sand in greenhouse 2 was shoveled from one side to the other and the plastic liner was replaced. Nothing was found in the old liner to indicate the cause of the leaks. While the sand was removed from the east ("low") bed, the sump was shortened to 26" to make it identical to the other houses. Then to be sure that rodents don't hurt the new liners, a layer of 2" concrete blocks was laid down on the bottom of both beds. Concrete was also molded to fill in the side walls and curves around the sumps. The new liners consisted of two layers of "tu-tuf-4" from Sto-cote Products, Inc. 1/, the same material the old liners were made from. A thin layer of sand was placed over the blocks, then the liners were put down, then the sump and drain tubes, and then the sand for the bed itself was shoveled back.

At the same time, the cooling systems for all four greenhouses were refurbished. Loose coating and corrosion were sandblasted off the cooling sumps and towers and spray chambers, and they were all recoated with cooler sealer.

Cultural procedures. A fall crop of tomatoes was sown in peat cubes on 11 July 1978 and transplanted into the greenhouse on 4 August 1978. The variety was changed to "N-65" from the University of Hawaii. The variety change was made because during the spring of 1978, "Tropic" had developed "Paul King's" disease, a yellowing between the veins of older leaves which progressively develops into necrotic tissue (Kimball and Mitchell, 1979d). Dr. Merle Jensen (Environmental Research Laboratory, University of Arizona, Tucson, personal

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1/ Trade names and company names are included for the benefit of the reader and do not infer any endorsement or preferential treatment of the product listed by the U. S. Department of Agriculture.

communication) reported that tobacco mosaic resistant plants like N-65 did not get the disease.

The greenhouse treatments were the same as for the 1977-78 winter crop. Briefly, house 1 was enriched to 1000 μℓ/ℓ whenever the greenhouse temperature was below 26.5 C. Above 26.5 C, conventional ventilation with evaporatively cooled air was started and the CO_2 enrichment was stopped. Greenhouse 2, the control house, was ventilated in the conventional way like house 1 above 26.5 C, and no CO_2 enrichment was done. Houses 3 and 4 were cooled with the cooling-tower systems above 26.5 C. Above 30 C, they were also ventilated with evaporatively cooled air. House 3 was enriched to 1000 μℓ/ℓ CO_2 and house 4 to 1350. No enrichment was done at night. All houses were electrically heated when the temperature decreased below 15.5 C.

As reported last year, the drip irrigation system has had a tendency to clog with calcium phosphates. To solve the problem, phosphoric acid (H_3PO_4) was used instead of KH_2PO_4 for the phosphorus source (Fontes, 1977). To compensate for the loss of K from the KH_2PO_4, more KNO_3 was added. Then to compensate for the added N from the KNO_3, the amount of $Ca(NO_3)_2$ was reduced. The final result was that the concentrations of all elements were the same as for the winter 1977-78 crop, except Ca, which was reduced from 177 to 126 ppm for the "low" concentration beds and from 240 to 161 ppm for the "high" concentration beds. The injector pumps again were operated in an alternating mode. That is, separate pumps were used for stock 1 containing the phosphate and stock 2 containing the calcium. A cam timer switched alternately from one to the other with water in between. The cycle was: 6 min stock 1, 6 min water, 6 min stock 2, 6 min water, etc. The clogging problem was greatly reduced using H_3PO_4 as the phosphorus source.

In spite of having fumigated all houses with 3 lb each of methyl bromide on 7 July 1978, a severe disease problem occurred with this

crop. During the month of November, a fungus disease which we believe was Botrytis cinera or gray mold became very prevalent in house 1. On 17 November 1978, the plants from this house were harvested for a final time and destroyed. The lower senescent leaves on the plants in the other houses were removed more generously than usual, and the plants were sprayed weekly with Benlate at a concentration of 2 tsp/gal of water. There was some loss of fruit in the other houses, but no losses of whole plants.

Another problem we found was that the variety, N-65, was partly determinant in its growth. Some of the plants in every house developed flower clusters from the apical bud and ceased vegetative growth. Other plants would send out a vigorous lateral shoot that was bigger than the apical shoot. Sometimes the lateral was mistaken for the apical shoot and the apical shoot was pruned instead. The result was highly variable plant heights because some of the plants were stunted at various times.

To have some measure of the statistical error in the plant yield data for the different treatments, five plants in the "low" beds and seven in the "high" beds were randomly selected, and the yields from these 48 plants were recorded individually starting on 27 October 1978.

On 20 March 1978, 10 tomatoes, and on 24 November 1978, 6 tomatoes, from each treatment were selected for Vitamin A and C analysis. They were chosen on the basis of appearing ripe and uniform. They were placed in labeled polyethylene bags and frozen overnight in a freezer. On the next day they were packed with dry ice and shipped to the Western Regional Research Center, Berkeley, California, courtesy of Dr. Gary M. McDonald, Research Chemist. They were kept frozen until time for the analyses.

The methods of analyses are described in Freed (1966). Briefly, one tomato comprised one sample. It was divided in two parts, one part was made into a 50% alcohol slurry and frozen for subsequent Vitamin C analysis; the other part was lyophilized and analyzed for Vitamin A.

The Vitamin A was analyzed as B-carotene by column chromatography purification and spectrophotometrically determining the concentration against a set of standards. B-carotene was converted to Vitamin A by the factor 0.60 mcg. of B-carotene equals 1 U.S.P. unit of Vitamin A as assigned by the United States Pharmacopeia.

The total Vitamin C analysis consisted of converting ascorbic acid to dehydroascorbic acid with bromine and determing the dehydroascorbic acid colorimetrically by coupling with dinitrophenylhydrazine.

Measurements. Most measurements were essentially as reported last year. Changes were as follows. First, a "saturn" radimeter was mounted on one of the storage cubicals about 10 m north of greenhouse 1 at about a 2-m height. The saturn senses downcoming thermal radiation from the sky needed in modeling the greenhouses' other devices. Second, the tube radiometers were removed from inside the greenhouses and routine measurements of solar radiation inside the greenhouse were stopped. Instead, on particular days, measurements of downcoming and reflected radiation inside the greenhouses were made using a tube solarimeter and a strip chart recorder. Measurements were made at four positions in each greenhouse. Third, thermocouples were installed in the soil in the back field about 2 m south of the fence and directly south of greenhouse 2. The depths were 25, 50, 100, 150, 200, and 250 cm. Holes were made with a pointed 1/4"-diameter rod. Then the thermocouples attached to 1/4" wooden dowels were inserted into the holes. The soil was packed around the dowels to complete the installation, and the voltages were recorded on the data acquisition system.

RESULTS:

Environmental Conditions. The environmental conditions for the fall 1978 crop outside and in the greenhouses are summarized in Tables 1 and 2. The conventionally cooled greenhouses (1 and 2) received an average of 41% of their solar radiation while not ventilated compared to 67% for the cooling tower systems (3 and 4). The inside average daytime air temperature ranged from about 27 C in August to 22 C in December. The corresponding nighttime temperatures ranged from 25

to 16 c. The relative humidity of the air in the conventionally ventilated, fan-pad cooled greenhouses varied from 66% during the day in August to about 80% during the day in November to about 85% at night in winter and summer. In the unventilated greenhouses, the relative humidity was close to 85% most of the time, decreasing in December when the heaters added dry heat.

The average day and night CO_2 concentrations by month are listed in Table 2. At night, respiration and the pilot lights on the CO_2 generators increased the CO_2 concentrations considerably above daytime values. The decreasing trend for the ventilated, ambient house probably is only partly real and may partly be due to our practice of calibrating the analyzers with 1000 ppm gas. Thus, they are more accurate near 1000 μℓ/ℓ than at lower ambient levels.

Yields: The marketable tomato yields for all plants are presented in Fig. 1, while those from the randomly selected individual plants are presented in Tables 3 and 4. The conventionally ventilated houses generally had higher yields than the unventilated, CO_2-enriched houses during October and November. The analysis of variance of the individual plant yields for the first half of November in Table 3 shows that indeed the ambient CO_2, ventilated house generally did yield significantly higher than the other greenhouses. In December, the CO_2-enriched houses outyielded the ambient house (Fig. 1) with the result in Table 4 that there was no significant difference in the 27 Oct - 2 Jan yields between the three greenhouses. Also, there was no significant difference due to nutrient concentration in either table.

The magnitude of the yields in Fig. 1 are roughly the same as found last year for the first 3 months (December, January, February) of the 1977-78 winter crop. For those first three months of that crop also, there was very little effect of the CO_2 enrichment on yield. The reason for a lack of response is not clear. It is consistent with the observation in the Northeast that spring crops outyield fall crops and respond more to CO_2 enrichment (Brooks et al.,

1973). This crop also had two problems that added uncertainty to the data. As mentioned earlier, the first was the tendency of some of the N-65 plants to be determinant and stop vegetable growth and/or produce particularly vigorous lateral shoots that could be mistaken for the apical shoot. The result was a variety of plant heights.

Superimposed on the variety-caused variability was the outbreak of Botrytis. Whether either of these problems was in fact more severe in the CO_2-enriched, unventilated houses and may have negated a positive response to CO_2 is unsure. However, these treated houses did have higher percentages of cull or unmarketable fruit than the control house as shown in Fig. 2. The cull percentage for the ambient CO_2, ventilated (control) house was a low 10%, while the CO_2-enriched, unventilated houses had percentages close to 20. The CO_2-enriched, ventilated house which had to be terminated had 35% culls, caused primarily by the Botrytis. If the unmarketable fruit yields are added to the marketable, the total fruit yields from the various houses are even closer than the marketable yields were alone.

Also shown in Fig. 2 are the average sizes of the marketable fruit. There was little difference between the treatments. The N-65 tomatoes were somewhat smaller than the tropic tomatoes reported previously. Tropic averaged about 0.22 kg/fruit compared to 0.18 for the N-65.

The total dry matter yield from the above ground plant parts is also shown in Fig. 3 with the exception of the CO_2-enriched, ventilated house that had the Botrytis outbreak. The control house produced slightly more dry matter at the standard nutrient level, but generally the differences were small.

<u>CO_2 recovery</u>: The amount of natural gas supplied to the greenhouses expressed as kg CO_2/plant is presented in Table 5. The fall months used more CO_2 than the summer because of less ventilation and more than the winter months because of longer days. The recovery percentages are slightly higher than last year, about 22 compared to 19%.

Infiltration: Table 6 presents results of some tests to measure the rate of air infiltration into the greenhouses. The CO_2 generators were turned on to raise the CO_2 concentration to high levels in the greenhouses and then turned off. Then the kg of concentration was plotted against time to determine the infiltration rate (air changes/hour) following Businger (1963) and also the velocity of air exchange per unit of wall area following Okada and Takakura (1973). Greenhouses 3 and 4 are better sealed than 1 and especially 2, as evidenced by the 0.48 and 0.64 air changes per hour for greenhouses 3 and 4 compared to 1.02 and 3.65 for greenhouses 1 and 2. The velocities calculated from the equation of Okada and Takakura (1973) came closer than expected to the measured values considering that they worked with glass houses, not fiberglass. Their equation appears to need an additional term to account for the extra exchange caused by the fans in the ducts of greenhouse 3 and 4 when they were on.

Vitamin A and C. The results from the 20 March 1978 tomato samples showed suspiciously low values of both Vitamin A and C. The average values were about 500 U.S.P. units/100 gm for A and 6 mg/100 g for C compared to Handbook (Watt and Merrill, 1963) values of 900 and 23 for A and C, respectively. Because the values were so low, they were not statistically analyzed and will not be presented. As a result of the March experience, additional checks were included for the analysis of the November samples. These included purchasing field- and greenhouse-grown tomatoes from a Phoenix market and freezing and shipping them along with the experimental tomatoes. Also fresh tomatoes were purchased from a Berkeley market and were analyzed for Vitamin C on the same day the frozen samples were analyzed.

The results are presented in Fig. 3 and Tables 7 and 8. First referring to Fig. 3 and Table 8, the Vitamin C contents from all the frozen samples were slightly lower than the fresh tomatoes and all were lower than the Handbook values. The difference wasn't of the same order of magnitude as the March samples, however, so it is probably safe to assume that the freezing, storage, etc. affected all treatments the same. Thus, continuing to focus on Vitamin C, the

"field" tomatoes had significantly less than most of the other treatments. There was no significant difference in Vitamin C among any of the treatments for the experimental tomatoes, nor were the "greenhouse" tomatoes significantly different.

Referring to Table 7 and Fig. 3, the "field" tomatoes had significantly less Vitamin C than the unventilated greenhouses and the high nutrient, 1000 μℓ/ℓ ventilated treatment. The "greenhouse" tomatoes were not significantly different from any of the treatments. The ambient CO_2, ventilated house had significantly lower Vitamin C than the CO_2-enriched houses with the exception of the standard nutrient treatment of the other ventilated.

Thus, we conclude that CO_2 enrichment and lack of ventilation did not harm the Vitamin A and C content of the tomatoes. Indeed, these treatments increased the Vitamin A content slightly.

Soil temperatures. In Figs. 4 and 5, the deep soil temperatures are plotted against time of year. The characteristic lag and damping of soil temperature is apparent. The 2.5-m depth reached a maximum 30.0 C in September whereas the average daily air temperature probably reached a maximum somewhat higher than 30 C during the July gap of the data.

Energy consumption. The length of time per month that the heating, cooling and emergency ventilation systems were in operation is listed in Table 9. December was unusually cold and the heaters were on more than 10 hrs per night. During August, all the coolers were in operation more than 12 hrs per day. The high humidity during this month made the unventilating cooling systems inadequate for 7 to 8 hours per day, so the emergency vents opened and CO_2 enrichment did not occur during these hours. During September, the emergency vents were open about 2-3 hrs per day, decreasing to only a few minutes on the average for the other months.

The energy consumed per plant is shown in Table 10. These data were computed from Table 9, using the power ratings for the various systems listed at the top of Table 10. The power ratings were determined from voltage and amperage measurements as discussed in the 1977

Annual Report. The unventilating cooling systems required about four times as much energy for cooling as the conventional cooling systems.

Water consumption. The amounts of water lost from the cooling and irrigation systems are listed in Table 11. The cooling system data are not very logical. In August when the emergency vents were open a large portion of the day, the water consumption of the unventilating cooling systems should have been about double instead of nearly equal the conventional system because evaporation could occur both in the cooling towers and the spray chambers on the greenhouses. Then in October the consumption should have been similar for the two systems instead of 3 to 5 times as much for the unventilating system. The water meters or leaks must have disturbed the cooling data. The evapotranspiration data are more logical with the conventional greenhouse using about twice as much water in accordance with their lower humidity (Table 1).

SUMMARY:

The yield response of tomatoes to CO_2 enrichment in unventilated greenhouses was evaluated. A 1977-78 winter crop of the "Tropic" cultivar gave yield increases of 50% with all of the benefit from CO_2 enrichment coming in the spring months. This was consistent with the first crop grown in spring 1977. Then a fall crop of "N-65" cultivar failed to show a significant response to CO_2. This crop suffered from a Botrytis outbreak and from being somewhat determinant in growth habit. Thus the lack of response with crop could possibly be attributed to the disease or growth habit or to just being fall.

Taste panels were conducted to see if the greenhouses were affecting tomato taste. There were no significant effects of CO_2 concentration, but lack of ventilation caused a small but statistically significant impairment of color, flavor, acceptability, and rank. Higher nutrient concentration caused a small but significant improvement of these same categories.

Sample tomatoes were frozen and shipped to the Western Regional Research Center, Berkeley, California, for Vitamin A and C analyses. The results showed that CO_2 enrichment and lack of ventilation did

not affect the Vitamin C content of the tomatoes, and actually increased the Vitamin A content slightly.

Additional data were obtained on the environmental conditions, energy consumption, and water consumption of the ventilated and unventilated greenhouses. The results were similar to last year with about 25° MJ/plant required for cooling the unventilated houses compared to 80 for the ventilated. The cooling water data were inconsistent, but the evapotranspiration data showed about 140 ℓ/plant of irrigation water were used in the unventilated greenhouses compared to 230 in the ventilated.

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PERSONNEL: B. A. Kimball, S. T. Mitchell, and D. S. Jones.

Table 1. Monthly average environmental conditions for the fall 1978 crop inside and outside the ventilated (V) and unventilated (U) greenhouses for all houses in a ventilation category.

	Solar radiation			Outside air temperature (°C)				Inside air temperature (°C)				Inside relative humidity (%)			
	Daily total MJ/m^2	While unventilated (%)		Dry bulb		Wet bulb		Day		Night		Day		Night	
		V	U	max	min	max	min	V	U	V	U	V	U	V	U
Aug	27.18	4	23	37.9	23.9	21.6	18.0	27.0	26.2	24.9	25.3	66	83	76	86
Sep	22.94	19	65	35.0	21.0	20.7	16.0	25.8	25.2	23.6	23.8	71	89	85	91
Oct	16.58	63	99	30.8	16.2	17.8	12.9	24.9	24.4	19.9	20.1	78	91	90	93
Nov	10.95	90	100	19.8	9.1	12.9	7.4	22.5	22.2	15.6	16.6	80	88	85	89
Dec	10.24	97	100	15.1	-3.6	9.7	-3.6	21.7	21.9	16.5	15.7	73	82	71	81
Avg for fall crop	17.58	41	67	27.7	13.3	16.5	10.1	24.4	24.0	20.1	20.3	74	87	81	88

Table 2. The average day and night CO_2 concentrations for the fall 1978 crop by month in the four greenhouses.

Month	Average CO_2 Concentration (μℓ/ℓ)							
	Day				Night			
Ventilation:[z]	V	V	U	U	V	V	U	U
Nominal CO_2:	amb.	1000	1000	1350	amb.	1000	1000	1350
August	461	496	710	750	531	924	1436	1239
September	438	566	769	969	488	1317	1614	1713
October	435	608	1012	1405	536	1675	1650	2223
November	320	778	973	1184	390	1177	1167	1463
December	247	622	1056	1186	289	596	870	1099
Average for fall crop	380	614	904	1099	447	1138	1347	1547

[z] V = ventilated with conventional fan-pad evaporation coolers at 26.5 C.

U = unventilated unless emergencies or humid weather forced ventilation at 29.5 C.

Table 3. Total marketable fruit yields of selected plants from 27 October to 17 November 1978 and analysis of variance (following Snedecor, 1956, p. 379) for the ventilated (V) and unventilated (U) greenhouses at various CO_2 concentrations and standard (S) and high (H) nutrient concentrations.

Plant No.	Marketable fruit (kg/plant)							
Ventilation:	V	V	U	U	V	V	U	U
CO_2 (μℓ/ℓ):	amb.	1000	1000	1350	amb.	1000	1000	1350
Nutr. Conc.	S	S	S	S	H	H	H	H
1	2.22	1.20	1.06	1.99	1.55	1.83	2.63	1.67
2	1.66	1.07	-	1.16	1.74	0.97	0.86	1.58
3	1.55	1.29	0.34	0.72	2.39	0.50	1.14	1.20
4	1.24	0.93	0.83	0.44	1.05	1.07	0.88	1.26
5	1.80	0.92	0.63	1.87	1.76	0.40	1.23	1.05
6					2.38	0.56	0.41	1.11
7.					3.76	1.30	0.89	1.57
Mean	1.69	1.08	0.72	1.24	2.09	0.95	1.15	1.35
	ab	bc	c	bc	a	c	bc	bc

Least Significant Difference (.05) = 0.66

Source of Variance	df	SS	MS	F
Concentration of nutrients	1		0.4267	1.36
Greenhouse (ventilation - CO_2)	3	6.8590	2.2863	7.27**
C x G	3	0.6005	0.2002	0.64
Error	39	12,2661	0.3145	

** Significant at 0.01

Table 4. Total marketable fruit yields of selected plants from 27 Oct 1978 to 2 January 1979 and analysis of variance (following Snedecor, 1956, p. 379) for the ventilated (V) and unventilated (U) greenhouses at various CO_2 concentrations and standard (S) and high (H) nutrient concentrations.

Plant No.	Marketable fruit (kg/plant)					
Ventilation:	V	U	U	V	U	U
CO_2 (μℓ/ℓ):	amb.	1000	1350	amb.	1000	1350
Nutr. Conc.:	S	S	S	H	H	H
1	4.38	9.88	5.15	6.86	7.91	5.22
2	6.49	7.09	3.27	6.12	5.63	5.63
3	–	5.10	3.63	4.56	4.73	3.11
4	2.49	3.79	1.51	4.05	5.61	3.60
5	7.36	4.47	4.09	7.59	4.66	2.12
6				6.84	3.99	3.75
7				6.09	4.51	5.53
Mean	5.18	6.07	3.53	6.02	5.29	4.14

Source	df	SS	MS	F
Total	34	136.17		
Treatment	5	29.14	5.83	1.58
Error	29	107.03	3.69	

Table 5. CO_2 consumption and CO_2 recovery percentage in plant dry matter for N-65 tomatoes, fall 1978, for the ventilated (V) and unventilated (U) greenhouses at various CO_2 enrichments.

Month	CO_2 Supplied (kg/plant)				CO_2 Recovered (% of supplied)		
Greenhouse No.:	1	3	4		1	3	4
Ventilation:	V	U	U		V	U	U
CO_2 (μℓ/ℓ):	1000	1000	1350		1000	1000	1350
Aug	0.85	0.64	0.85		0	2	1
Sep	1.12	1.28	– *		4	3	– *
Oct	1.39	1.92	2.46		29	19	17
Nov	1.34	1.50	1.71		45	23	19
Dec	–	1.71	1.60		–	46	49
Total	4.45	7.05	6.62 *	Average	21	22	24*

* Gas meter malfunctional and had to be replaced during September.

Table 6. Greenhouse air infiltration rates and wall air velocities (3 August 1978).

Greenhouse No.	Conditions: temperature inside (c)	temperature outside (c)	wind speed (m/s)	cooling system fan [z]	Infiltration Rate (air changes/hr)	Volume (m^3)	Wall area (m^3)	Wall air velocity: Measured ($m^3 m^{-2} hr^{-1}$)	Calculated [y] ($m^3 m^{-2} hr^{-1}$)
1	24.8	25.0	1.42	off	1.02	90.3	101.0	0.91	0.69
2	24.8	25.0	1.53	off	3.65	82.5	66.8	4.51	0.74
	25.1	25.0	1.26	off	2.19	82.5	66.8	2.71	0.60
3	25.7	25.0	1.42	off	0.64	90.3	101.9	0.57	0.74
	28.6	28.1	1.04	on	1.31	90.3	101.9	1.16	0.56
	29.3	29.2	1.30	on	1.74	90.3	101.9	1.54	0.62
4	25.9	25.0	1.42	off	0.48	90.3	101.9	0.43	0.76
	28.1	28.1	1.26	on	1.45	90.3	101.9	1.28	0.55

[z] When the cooling system fan was off, small circulation fans were on in the greenhouses.

[y] $V_w(m^3 m^{-2} C^{-1}) = 0.44 * U\ (m/s) + 0.14 * \left[\Delta T^{1/2}\ (°C)\right]$ from Okada and Takakura (1973).

Table 7. Analysis of variance (following Snedecor 1956, p. 270) of Vitamin A content of N-65 tomatoes for ventilated (V) and unventilated (U) greenhouses at various CO_2 concentrations and standard (S) and high (H) nutrient levels. The tomatoes were sampled on 13 November 1978. The "greenhouse" and "field" tomatoes came from a Phoenix market. Analyses were performed courtesy of the Western Regional Research Center, Berkeley, California.

Sample No.	Vitamin A (USP units/100 g)									
Ventilation:	V	V	U	U	V	V	U	U		
CO_2 (µℓ/ℓ):	amb.	1000	1000	1350	amb.	1000	1000	1350		
Nutr. Conc.:	S	S	S	S	H	H	H	H	field	greenhouse
1	633	550	650	700	550	900	733	667	367	767
2	533	650	883	750	500	900	817	883	667	733
3	617	567	650	–	583	867	767	550	–	633
4	617	617	–	833	633	–	833	750	550	533
5	417	667	833	733	633	483	800	933	500	600
Mean:	563	610	754	754	580	788	790	757	521	653
	c	bc	ab	ab	c	a	a	a	c	abc

Least Significant Difference (.05) = 145

Source of Variance	df	SS	MS	F
Concentration of nutrient	1	29 587	29 587	2.53
Greenhouse (Ventilation-CO_2)	3	233 042	77 681	6.65 *
C x G	3	43 837	14 612	1.24
Error	29	339 007	11 690	

* Significant at 0.05

Table 8. Analysis of variance (following Snedecor, 1956, p. 379) of vitamin C content of H-65 tomatoes for ventilated (V) and unventilated (U) greenhouses at various CO_2 concentrations and standard (S) and high (H) nutrient levels. The tomatoes were sampled on 13 November 1978. The "greenhouse" and "field" tomatoes came from a Phoenix market and were frozen with the other tomatoes. The "fresh" tomatoes came from a Berkeley market and were never frozen. Analyses were performed courtesy of the Western Regional Research Center, Berkeley, California.

Sample No.	Vitamin C (mg/100 g)										
Ventilation:	V	V	U	U	V	V	U	U			
CO_2 (μℓ/ℓ):	amb.	1000	1000	1350	amb.	1000	1000	1350			
Nutr. Conc.:	S	S	S	S	H	H	H	H	field	greenhouse	fresh
1	13.4	12.2	16.7	16.4	15.3	14.3	14.0	12.1	9.9	18.6	18.5
2	10.1	17.6	14.2	15.6	15.3	14.8	12.4	16.0	11.9	13.1	17.3
3	14.7	12.8	15.9	15.5	11.8	13.6	13.9	14.4	11.2	12.9	17.7
4	14.4	12.1	15.7	14.7	13.9	21.6	13.3	15.1	9.0	9.6	17.1
5	11.9	18.4	15.1	14.2	12.3	14.5	11.3	14.0	12.1	11.8	19.1
Mean:	12.9	14.6	15.5	15.3	13.7	15.8	13.0	14.3	10.8	13.2	17.9
	de	bcd	abc	bcd	bcd	ab	cde	bcd	e	bcde	a

Least Significant Difference (.05) = 2.6

Source of Variance	df	SS	MS	F
Concentration of Nutrient	1	1.482	1.482	0.37
Greenhouse (Ventilation - CO_2)	3	19.941	6.647	1.67
C x G	3	21.881	7.294	1.83
Error	32	127.420	3.982	

Table 9. Monthly time of operation of heating, cooling, and emergency ventilation systems, 1978.

	Greenhouse No. and Ventilation Type											
	1			2			3			4		
	Ventilated			Ventilated			Unventilated			Unventilated		
Month	heat	cool	vent	heat	cool	vent	heat	cool	vent	heat	cool	vent
	(hours)											
May	2	46	-	13	110	0	12	24	0	30	94	0
1 - 12 June	0	24	-	0	90	0	0	17	0	4	55	0
Fall crop (4 August 1978 - 2 January 1979)												
August	0	408	-	0	363	10	0	391	216	0	355	244
September	1	280	-	3	283	0	2	342	110	1	315	161
October	2	83	-	11	120	0	10	236	3	4	227	4
November	27	33	-	152	7	0	153	63	1	118	56	0
December	344	25	-	337	1	0	373	15	0	300	11	0
Total for crop	374	829	-	503	774	10	538	1047	330	423	964	409

Table 10. Energy consumption, 1978.

	Greenhouse No. and Ventilation Type							
	1		2		3		4	
	Ventilated		Ventilated		Unventilated		Unventilated	
Month	heating	cooling	heating	cooling	heating	cooling	heating	cooling
	(MJ/plant *)							
Power (kw):	6.85	1.47	6.85	1.29	6.85	3.39	6.85	3.65
May	1	5	6	10	6	6	15	25
1 - 12 June	0	3	0	8	0	4	2	14
Fall crop (4 August 1978 - 2 January 1979)								
August	0	43	0	34	0	95	0	93
September	0	30	1	26	1	83	0	83
October	1	9	5	11	5	58	2	60
November	13	3	75	1	75	15	58	15
December	170	3	166	0	184	4	148	3
Total for crop	185	88	248	72	265	256	209	253

* MJ/plant = (hours) x (kw) x (3600 sec/hr) x (1000 $\frac{J/S}{kw}$) x (10^{-6} $\frac{MJ}{J}$)/(50 plants)

Table 11. Water consumed by the cooling systems, supplied to the plants by the irrigation system, and evapotranspired from soil and plants, 1978.

Month	Cooling Water Greenhouse No. 1 & 2	Cooling Water Greenhouse No. 3	Cooling Water Greenhouse No. 4	Avg. Irrigation Water	Evapotranspiration Greenhouse No. - Ventilation 1-V S	1-V H	2-V S	2-V H	3-U S	3-U H	4-U S	4-U H
	(ℓ/plant)											
May	176	553	821	58	42	7	45	40	35	41	56	42
1-12 June	125	616	198	31	22	22	24	18	18	20	39	19
Fall crop (4 August 1978 - 2 January 1979)												
August	797	880	956	83	31	29	41	34	22	20	14	8
September	395	676	1005	99	67	60	82	66	9	49	60	46
October	169	1192	535	46	48	39	64	56	53	33	38	24
November	16	90	97	58	9	5	31	18	17	17	13	1
December	0	20	29	83	-	-	30	42	11	37	33	34
Total for crop	1377	2858	2622	369	-	-	248	216	112	156	158	113

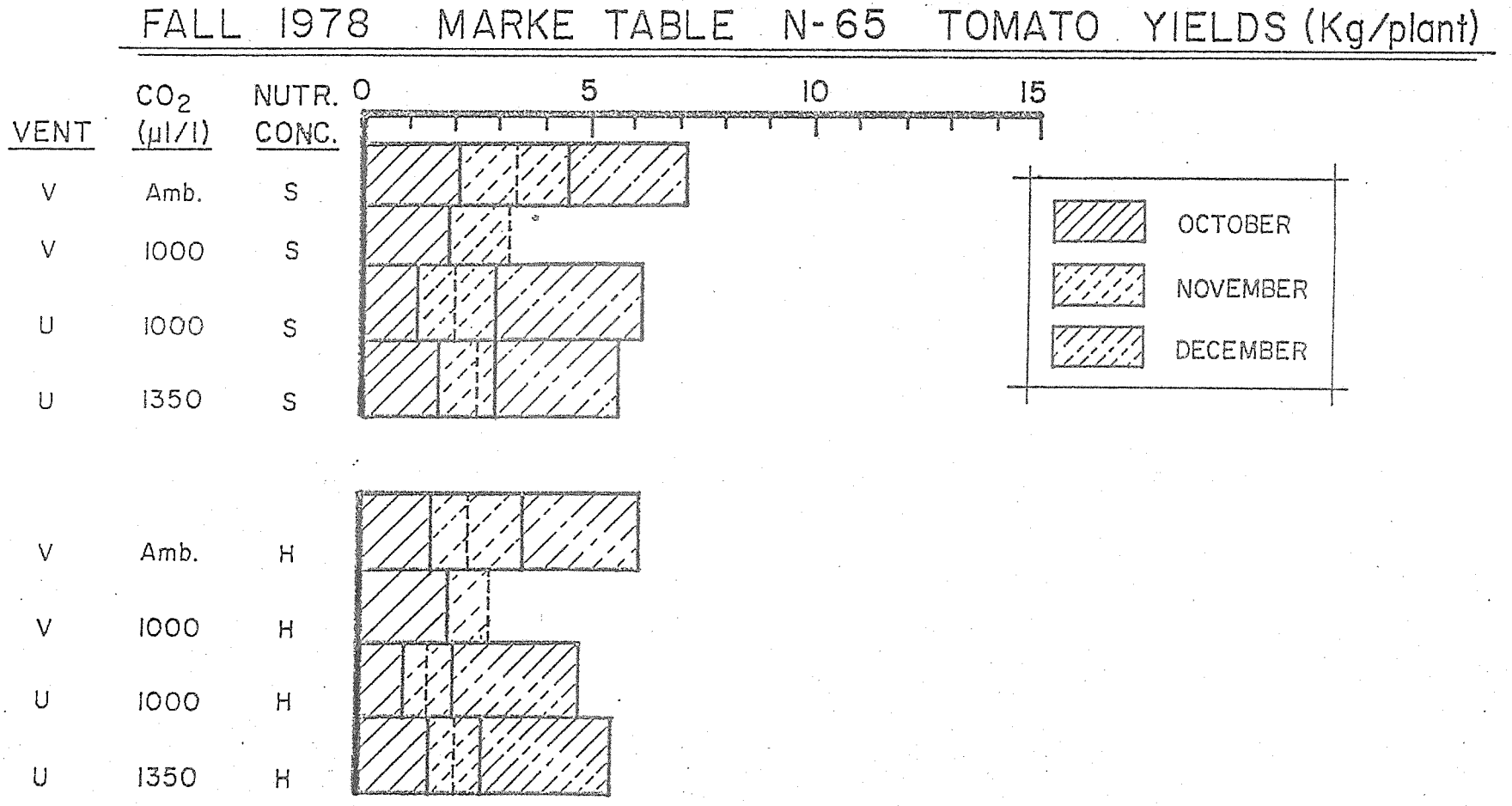

Figure 1. Mean yields of marketable N-65 tomatoes from ventilated (V) and unventilated (U) greenhouses at various CO_2 enrichments and at standard (S) and high (H) nutrient concentrations. The dashed lines are the cumulative yields on 17 November 1978 when house 1 was terminated because of grey mold. The November plus December yields were not significantly different at 5%.

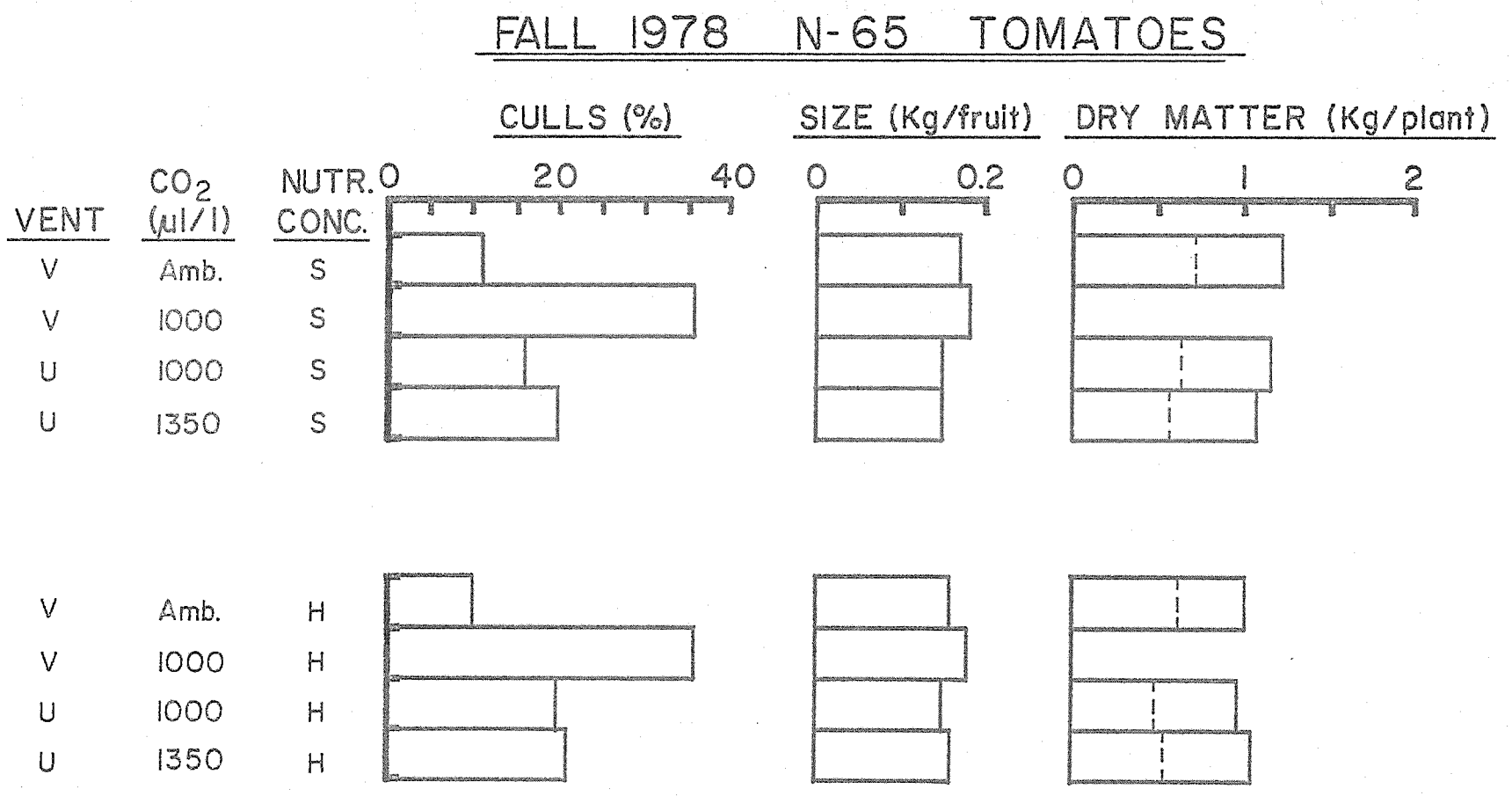

Figure 2. Percent of unmarketable culls (kg culls x 100/kg total fruit), average marketable fruit size and total above ground dry matter production from ventilated (V) and unventilated (U) greenhouses at various CO_2 enrichments and at standard (S) and high (H) nutrient concentration. The dashed lines show the amount of dry matter produced from the marketable fruit.

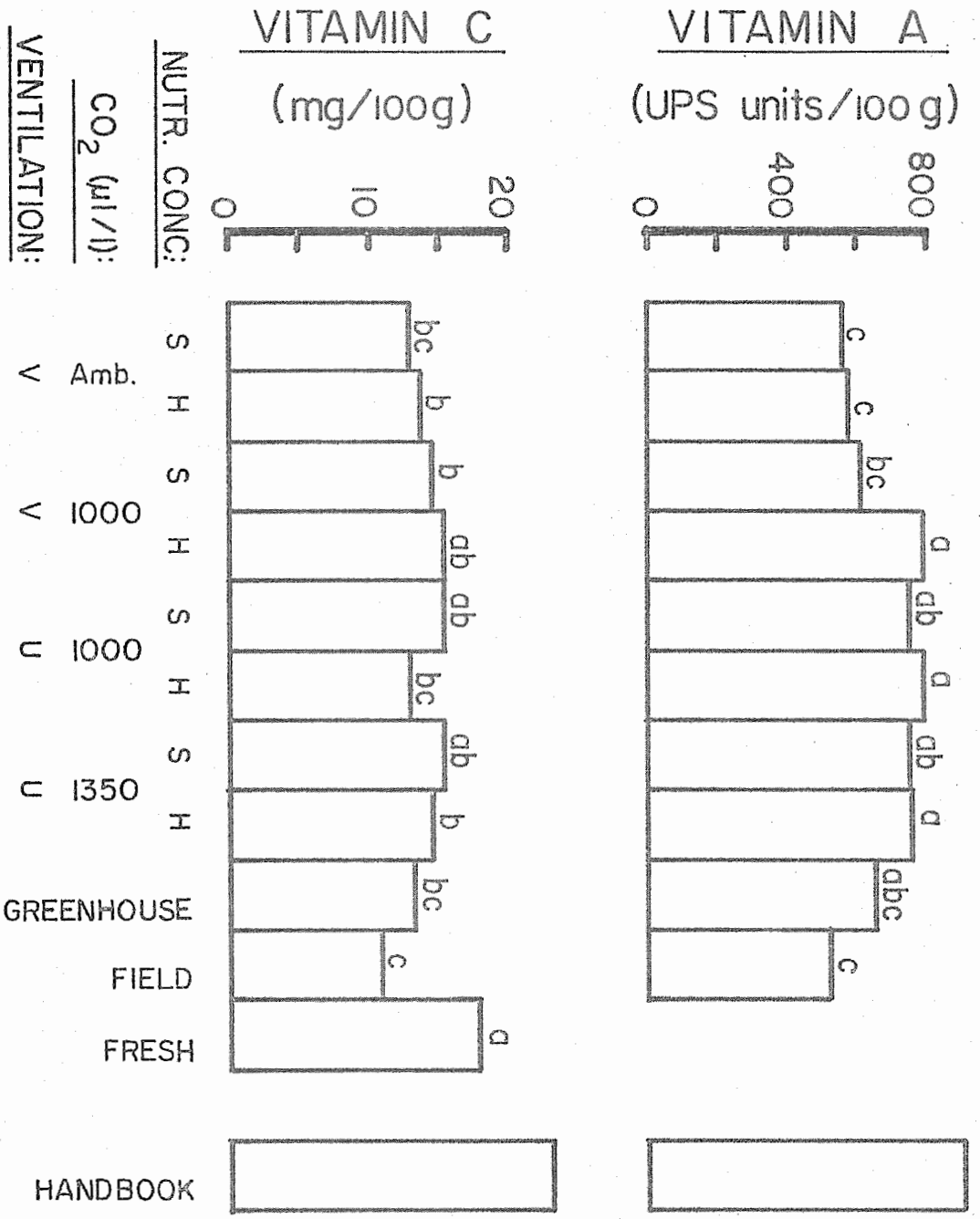

Figure 3. Vitamin A and C content of N-65 tomatoes sampled 13 November 1978 for ventilated (V) and unventilated (U) greenhouses at various CO_2 concentrations and standard (S) and high (H) nutrient levels. The "greenhouse" and "field" tomatoes came from a Phoenix market and were frozen with the other tomatoes. The "fresh" tomatoes came from a Berkeley market and were never frozen. The "handbook" values are from Watt and Merrill (1963). Analyses were performed courtesy of the Western Regional Research Center, Berkeley, California.

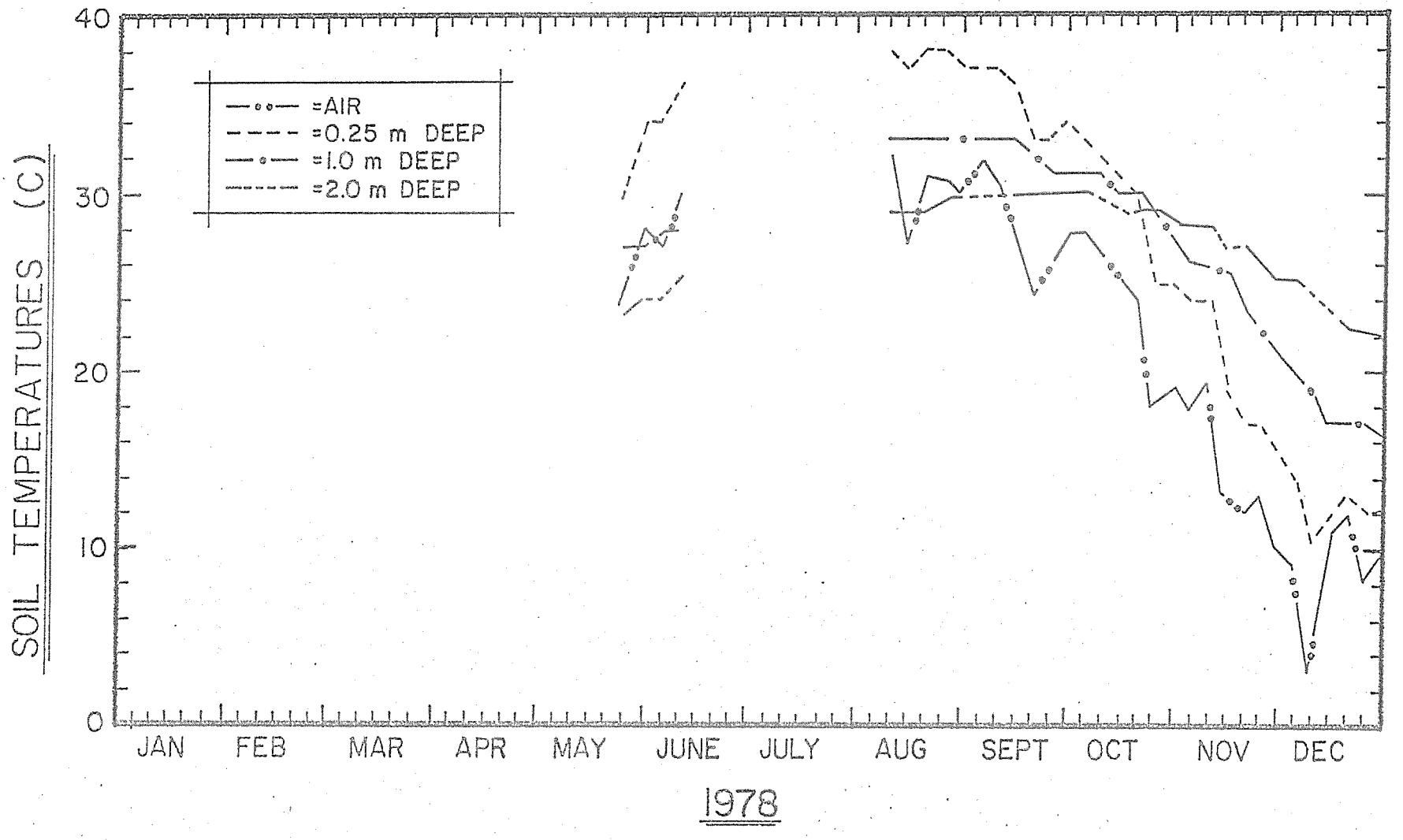

Figure 4. Soil temperatures at midnight and average daily air temperatures for bare Avondale loam in Phoenix, Arizona, for 1978.

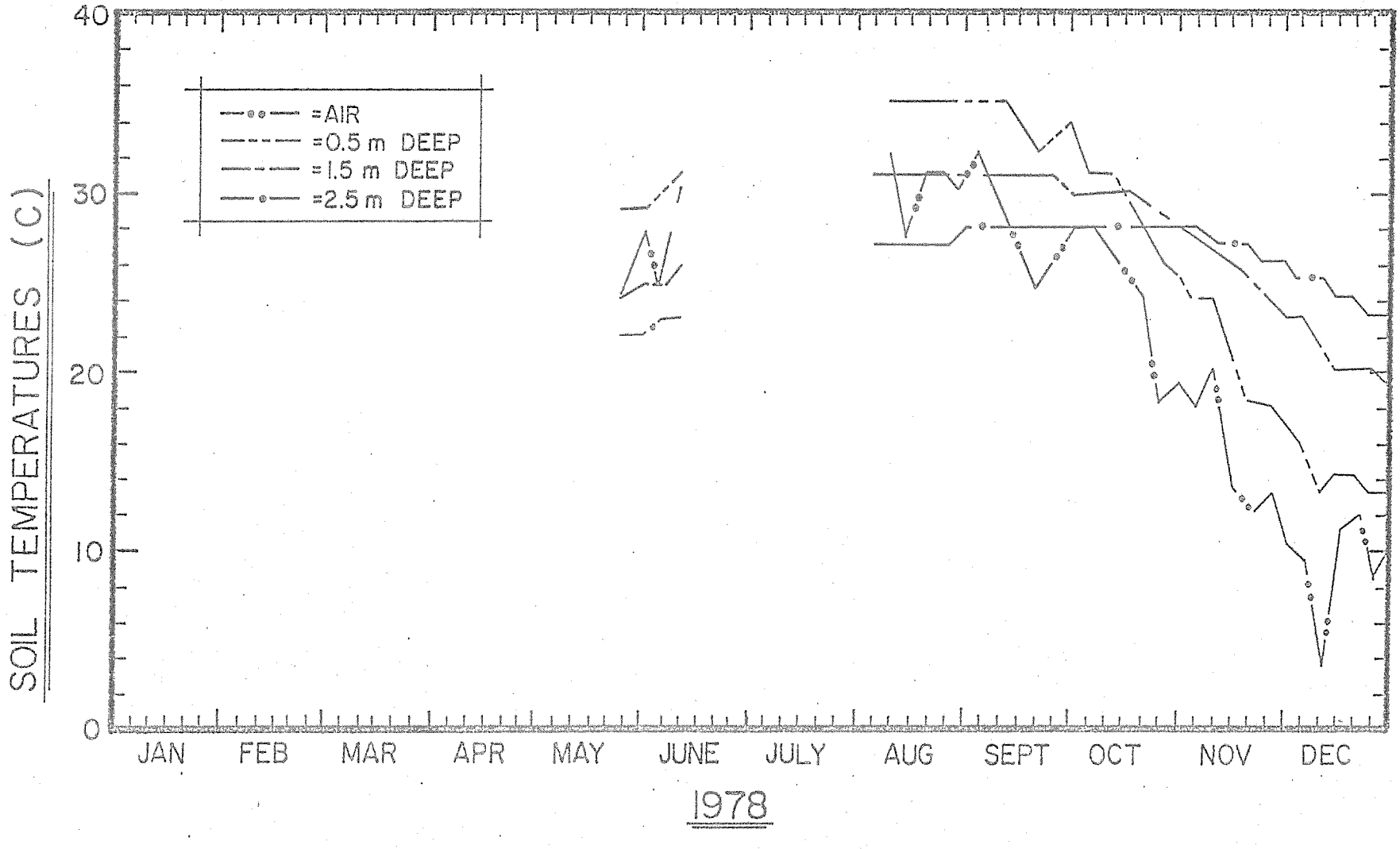

Figure 5. Soil temperatures at midnight and average daily air temperatures for bare Avondale loam in Phoenix, Arizona, for 1978.

TITLE: WASTEWATER RENOVATION BY SPREADING TREATED SEWAGE FOR GROUNDWATER RECHARGE

NRP: 20790 CRIS WORK UNIT: 5510-20790-001

CODE NO.: Ariz.-WCL 67-4

INTRODUCTION:

The research at the Flushing Meadows Project abruptly came to a halt on 3 March 1978 because severe rain on the watershed of the Salt and Verde Rivers forced the release of water from the reservoirs at a rate that peaked at about 145,000 cfs. This flooded the Flushing Meadows Project, knocking down the fence, filling the basins with sediment, and cutting a new effluent channel through the access road while covering the concrete bridge over the old channel with sand. The project got flooded again in December 1978, when a large flow was also released from Lake Pleasant on the Agua Fria River. The future of the Flushing Meadows Project is uncertain at this time.

The 23rd Avenue Project was not operated at all in 1978 because of a delay in the construction of the by-pass channel in the 80-acre pond.

The primary-effluent recharge project at the Mesa Sewage treatment plant was operated during the entire year of 1978.

Dr. J. C. Lance returned from his temporary assignment with the National Program Staff in Beltsville in July 1978.

I. FLUSHING MEADOWS PROJECT

1. Basin Management and Infiltration Rates.

Since the NH_4-N content of the renovated water in 1977 was still on a downward trend following a change in 1974 to a 9-day-flooding 12-day-drying mode at 6-inch water depth, this schedule was continued in 1978. The condition of the basins was about the same as in 1977, i.e. bare soil and a 3/8-inch sludge layer (dry) for basin 1, gravel layer with 3/8-inch sludge layer for basin 2, old vegetation remnants (bermudagrass, sudangrass) and 3/8-inch sludge layer in basins 3, 4, 5, and 6.

Infiltration rates for the three periods are shown in Figure 1. Records were available only for the first two flooding periods. The graphs for the third period were still on the water-stage recorders

when the March flood hit. Thus, infiltration rates for the third flooding period have been extrapolated from those for the first two. The total infiltration for the three periods was 41 ft (average for the six basins). Adding this to the previous cumulative infiltration of 2473 ft yields a total accumulated infiltration of 2514 ft for the life of the project from September 1967 to March 1978.

2. Nitrogen.

The total-N concentration of the secondary effluent averaged 33.2 mg/l, of which 31.2 was NH_4-N, 0.16 NO_3-N, and 1.9 organic N. With the exception of one high value, there was not too much scatter in the total-N content of the effluent (Figure 2). Most well samples showed the typical NO_3-N peaks in the renovated water due to the arrival of effluent water that infiltrated in the beginning of a flooding period and leached nitrate formed during drying in the upper soil layers (Figures 2 and 3). The NH_4-N concentrations in the renovated water generally were below 1 mg/l, except for ECW where it climbed to about 4 mg/l (Figures 2 and 3). Average N-concentrations in mg/l for the renovated water were

	NO_2-N	NO_3-N	NH_4-N	Organic-N	Total N
Well 1	0.29	10.5	0.3	0.6	11.7
Well 1-2	0.04	5.1	0.6	0.2	5.9
ECW	0.14	4.1	2.3	1.1	7.6
Well 5-6	0.04	8.3	0.24	0.55	9.1
Well 7	1.28	7.1	0.01	0.33	8.7

The N-removal appears to be about the same as in 1977, when it averaged 63 percent for the wells 1-2, ECW, and 5-6 between the basins.

3. Phosphate.

Average PO_4-P concentrations and removal percentages were

	PO_4-P mg/l	Removal %
Effluent	8.12	
Well 1	0.8	90
Well 1-2	3.1	62
ECW	1.7	79
Well 5-6	2.47	70
Well 7	0.19	98

Graphs of PO_4P concentrations in effluent and for renovated water from various wells are shown in Figure 4. The relatively high PO_4-P concentrations in the renovated water from shallow wells 1-2 and 5-6 as compared to the lower concentrations in the deeper ECW and outlying wells 1 and 7 indicate that PO_4-removal continued with additional travel of the renovated water in the aquifer.

4. Organic Carbon.

TOC concentrations were determined with the Technicon Auto-analyzing equipment, which was acquired to replace the aging Beckman 915. The following results were obtained

	TOC (range) mg/l	TOC (average) mg/l
Effluent	8.2-12.3	10.5
Well 1	1.5-4.1	2.1
Well 1-2	2.5-5.9	3.8
ECW	2.4-5.7	3.7
Well 5-6	1.6-5.1	2.8
Well 7	1.4-4.3	2.1

These values were about 50 percent lower than those obtained with the Beckman 915 in 1977. TOC contents were higher in renovated water from the shallow wells between the basins than in that from the deeper well

between the basins and the outlying wells, indicating continued removal of organic carbon with additional movement of renovated water through the aquifer. Since adsorption probably is no longer a factor after 10 years of operation and a total infiltration of 2514 ft, the removal of organic carbon must be by biological degradation and perhaps volatilization. Progress toward identifying the trace organics has been made with the Western Regional Research Center.

5. Other Chemical Parameters.

Analyses of TDS, boron, fluoride, and fecal coliform concentrations were not made in 1978, since these parameters were frequently determined in 1977.

6. Summary and Conclusions.

Since the Flushing Meadows Project was flooded out in early March due to river flows that were on the order of the 50-year recurrence interval, data could only be obtained for January and February. The flooding sequence in those months was continued at 9 days flooding and 12 days drying, yielding three flooding periods. Accumulated infiltration for these flooding periods was 41 ft (average for the six basins). This brought the total infiltration since the start of the project in September 1967 to 2514 ft. Average nitrogen content of the sewage effluent was 33.2 mg/l (31.2 as NH_4-N) and of the renovated water sampled from the three wells between the basins 7.5 mg/l (5.8 as NO_3-N and 1.0 as NH_4-N). Nitrogen removal thus was on par with that of 1977, when it averaged 63 percent for the three wells between the basins. Average PO_4-P concentrations were 8.12 mg/l for the effluent, 2.4 mg/l for the wells between the basins, and 0.5 mg/l for the outlying wells. This indicates continued removal of PO_4 as the renovated water moves in the aquifer, producing more than 90 percent removal 100 ft away from the basins. A similar pattern was observed for the organic carbon. TOC values averaged 3.4 mg/l for renovated water from the wells between the basins, and 2.1 mg/l for that from the outlying wells. The TOC-content of the effluent averaged 10.5 mg/l. The renovation efficiency of the Flushing Meadows

Project thus continued unabated, even after more than 10 years of recharge and a total infiltration of 2514 ft.

II. 23rd AVENUE PROJECT

The purpose of the by-pass channel in the 80-acre pond is to allow secondary effluent from the 23rd Avenue Treatment Plant to directly enter the infiltration basins. Previously, the effluent was passed first through the 80-acre pond. This was undesirable, because heavy algae growth in the summer greatly increased the suspended solids content of the effluent, which in turn produced low infiltration rates in the infiltration basins because of soil clogging. When the by-pass construction was advertised in March 1978, there were no bidders because of a heavy demand for earth work in the valley. The project was then combined with some other earth moving jobs at the sewage treatment plant and advertised again in November 1978. This time, there were several bidders, the contract was awarded in January 1979, and construction was to start about 22 January 1979. The 23rd Avenue rapid-infiltration system thus can be expected to be operational again by about April 1979.

The March flow in the Salt River caused a temporary rise in the water table in the vicinity of the riverbed, due to seepage and groundwater recharge. Since it is possible to calculate hydraulic properties of the aquifer from the rise and fall of the groundwater mound in response to a recharge event, water levels were measured in the north observation well of the 23rd Avenue Project. The resulting hydrograph (Figure 5) may be used in calculating hydraulic properties of the aquifer for future analyses of the underground flow system below the 23rd Avenue recharge basins.

III. MESA PRIMARY EFFLUENT PROJECT

Field studies using primary effluent were continued at the Mesa Sewage Treatment Plant (see 1977 Annual Report). The main objective was to determine the optimum operating conditions for maximizing the hydraulic loading.

1. Infiltration Rates.

The infiltration schedule from January to mid-April was 1 week flood and 2 weeks dry. During the remainder of the year a 1 week flood and 1 week dry schedule was followed with a 2-week dry-up every three to four cycles. The infiltration rates are shown in Figures 6 to 9 for the four basins. The infiltration capacity did not recover adequately with a 2 week dry-up in the winter months. Starting in March the surface was scarified by raking, resulting in a substantial increase in infiltration. Prior to raking, the weekly infiltrations were 1.0, 1.3, 1.9, and 1.8 ft/week for basins 1, 2, 3, and 4, respectively. After raking, the infiltration for the respective basins was increased to 6.6, 4.0, 3.9, and 3.7 ft/week. The infiltration for each weekly flooding period is shown in Figures 10 to 13, along with the raking schedule. After the raking started, the infiltration rate in basin 1 was considerably higher than the other three basins. Particle size analysis for basins 1 and 2 (see Table 1) shows that basin 1 contains about 20 percent more sand than basin 2 in the top 20 cm and, consequently, results in a higher infiltration rate. The infiltration rate in basin 1 was more susceptible to raking than the other basins, probably due to the higher sand content. During June when basin 1 was not raked, the infiltration rate decreased for each succeeding period. The absence of raking during two successive periods in basin 2 did not affect the infiltration rate during the same time period. During November infiltration rates were lower and raking did not increase the value to the summer levels. The 1 week drying time was not adequate to rejuvenate the infiltration rate.

A 2-inch layer of mortar sand was placed in basin 4 in July. Because the coarser sand would have a lower water-holding capacity, the surface would dry out faster and break the capillary water

supply to the surface. Rapid drying of the surface was observed. The surface was visibly drier after 1 day of drainage during the summer and 3 days drainage during the winter. The sludge layer had shrunk away from the sand leaving a relatively open surface. There appears to be little or no benefit to the hydraulic loading, however. During the colder winter months when maximum benefit from rapid drying would be expected, the same trend of decrease in infiltration was noted in basin 4 as in the other basins. While the surface does dry out faster, the profile remains wetter for a longer time. This is shown in Figure 14 where the pressure head at the 13 and 41 cm depth is shown. Before July the minimum pressure head after 7 days drying was about -109 cm and -67 cm for the 13 and 41 cm depths, respectively. After the sand was added, the minimum pressure head increased to -89 cm and -53 cm for the same depths. The soil, therefore, remains at a higher water content for a longer period of time. While the surface does dry out faster, evaporation from the profile is prevented and the sand layer acts as a mulch.

Basins 3 and 4 received effluent that had first passed through a sedimentation pond. In August the supply to basin 4 was fed directly into the basin, by-passing the sedimentation pond. There is no apparent benefit due to the sedimentation basin. The average suspended solids content of the primary effluent before and after the sedimentation basins was 56 and 68 mg/liter, respectively. The solids in the effluent are very fine and stay in suspension for long periods of time. The detention time in the sedimentation pond was long enough to permit some algal growth, resulting in an increase in suspended solids. By-passing the sedimentation pond had no noticeable effect on the infiltration of basin 4.

The suspended solids content of the primary effluent did show a gradual decrease from 75 mg/liter in January to about 40 mg/liter in September, and then an increasing trend toward the end of the year (Figure 15). Using an inundation schedule of 1 week flood and 2 weeks dry during December, January, and February, and then a 1 week flood, 1 week dry schedule for the remainder of the year, 110 to

470 ft/year of primary effluent could be infiltrated. Scarifying the surface would be necessary for each inundation period during the colder winter months and every two to three inundations during the summer.

2. Quality of Infiltration Water.

Qualitative analysis of the infiltrating water was done on samples taken from porous ceramic cups placed in the soil. A vacuum was applied to the ceramic cups and samples were obtained in that manner. From January to May, 10 to 100 ml samples were obtained during a 1-hour time interval each day when the basins were flooded. No samples were taken during the dry period. From May to December the vacuum was applied to the ceramic for 5 to 10 minutes each hour using a timing system. The sample was collected in a water trap that was stored in an insulated, ice-cooled box. In this manner a composite 24-hour sample was obtained.

Average concentration of ammonia-N, organic-N, phosphate-P, and total organic carbon are summarized in Table 2 for primary effluent and samples taken from the ceramic cups. Total N of the effluent averaged 28.3 mg/liter with 4 mg/liter being organic-N. Average ammonia concentrations at the 10-cm depths were 15, 18, 2, and 1 mg/liter for basins 1, 2, 3, and 4, respectively. The organic-N was between 1 and 3 for the four basins. Ammonium levels were higher at both depths in basins 1 and 2 than in basins 3 and 4. The presence of the sand layer in basin 4 did not affect the quality of the soil-water. Nitrate-nitrogen concentrations for the four basins are shown in Figures 16, 17, 18, and 19. A nitrate peak was noted during the first or second day of inundation at both depths. Very high concentrations of nitrate-N (300 to 900 mg/liter) were measured on several occasions when the first water infiltrating was sampled. The very high concentrations occurred during the January to May time period when sampling was done just after the basins had been flooded. Commencing with the 24-hour composite sampling, the concentrations during the first day were considerably lower. On a

ew occasions a 200 mg/liter NO_3-N concentration was obtained, but the peak for the most part was below 100 mg/liter.

Because the ammonium levels were higher in basins 1 and 2 than in basins 3 and 4, an additional set of ceramics was installed in asin 2 at depths of 10 and 56 cm. The average concentration of nitrate, ammonium, and phosphate during four flood periods are shown n Table 3 for the old and new ceramics. The ammonium and nitrate levels from the new ceramic samplers were about half of the concen-ration of the old ones, except for the 10 cm ammonium levels where the values were about the same. The phosphate levels differ by about 20 percent.

The wide variation in concentrations from two sampling points indicates that a large number of samplers must be used to obtain reliable quantitative results.

The average phosphate-P concentrations of the primary effluent were 5.5 mg/liter. The phosphate-P concentrations at the basins are shown in Table 2. In basins 1 and 2 the phosphorus level increased . mg/liter at the 10-cm depth. In basin 2, the level dropped to 0.9 mg/liter at the 56-cm depth. Basins 3 and 4 showed smaller decreases at the lower depths. The overall phosphorus reduction for all four basins is 40 percent.

3. Cost Analysis.

Cost comparison between land treatment of primary effluent and secondary activated sludge treatment was made using EPA guidelines and is summarized in Table 4. Land treatment is less costly for plant sizes from 1 to 100 mgd and uses about 20 percent less elec-trical energy. Most of the electrical energy required in land treatment is for reclaiming the water by pumping.

4. Summary.

Studies on land applications of primary effluent using infil-tration basins were continued to determine the optimum operating conditions for maximizing the hydraulic loading. Low infiltration rates were observed during the colder winter months. Changing the flooding schedule from 7 day flood - 7 day dry to 7 day flood -

14 day dry did not result in increased infiltration. Scarifying the surface layer by raking did result in a 2- to 4-fold increase in infiltration. Scarifying the surface is necessary after each flooding during the winter and after two or three floodings during the summer. The weekly infiltration after scarifying ranged between 3 and 9 ft with an average of 4.6 ft. The basin that had the highest infiltration rate (7.3 ft/week) also had the highest percentage of sand in the top 20 cm (74 percent compared to 54 percent for the other basins). By using a 1 week flood - 2 week dry schedule for December, January, and February, and a 1 week flood - 1 week dry schedule for the remainder of the year, a hydraulic loading rate of 110 to 170 feet/year could be expected. The estimated cost of treating 10 million gallons/day of primary effluent for the above loading rates would be 6¢ to 8¢/1000 gal. Conventional secondary treatment alone costs about 12¢/1000 gal and uses 23 percent more electrical energy than land treatment.

PERSONNEL:* H. Bouwer, R. C. Rice, G. C. Emery

*U.S. Water Conservation Laboratory personnel for all three projects.

Table 1. Soil particle size analysis for basins 1 and 2.

Basin	Depth cm	Sand	Silt	Clay
		%		
1	0-1	65	28	7
	1-10	72	21	7
	10-20	86	11	3
2	0-1	56	35	9
	1-10	56	35	9
	10-20	49	42	9

Table 2. Average concentrations of NH_4-N, organic N, PO_4-P, and dissolved organic carbon in the primary effluent and soil solution for the different basins.

Location	Depth	NH_4-N	Organic N	PO_4-P	Carbon
	cm	mg/1			
Effluent	-	24.0	4.3	5.5	24
Basin 1	10	15.0	2.5	6.7	16
Basin 1	56	8.4	1.7	5.3	15
Basin 2	10	18.1	3.1	6.5	21
Basin 2	56	9.6	2.4	0.9	18
Basin 3	10	2.0	1.0	4.7	10
Basin 3	46	1.2	1.1	4.3	9
Basin 4	10	1.0	1.7	3.6	19
Basin 4	53	0.4	1.2	2.8	11

Table 3. Average NO_3-N, NH_4-N, and PO_4-P concentrations for new and old ceramic samplers in basin 2.

Date	NO_3-N				NH_4-N				PO_4-P			
Depth	10 cm		56 cm		10 cm		56 cm		10 cm		56 cm	
	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New
17-13 July	8.0	0.05	25.0	9.3	18.4	24.3	18.9	8.8	7.3	6.1	0.7	1.3
21-27 July	8.6	.26	11.8	7.3	20.3	24.1	14.7	5.0	8.9	7.9	.7	1.1
4-10 August	10.1	.8	2.4	3.7	17.3	16.0	11.3	3.7	5.3	3.1	.7	1.8
25-31 August	3.6	11.7	5.3	3.7	15.8	6.3	7.8	4.0	6.8	5.2	.8	1.5
11-14 September	-	-	9.7	5.2	-	-	5.4	3.2	-	-	.9	1.3
Average	7.6	3.2	10.8	5.8	18.0	17.7	11.6	4.9	7.0	5.6	.8	1.4

Table 4. Cost Comparison of Treating Primary Effluent Using Land Treatment and Activated Sludge.

Quantity mgd	Treatment[a/]	Energy required, kwh/day	Land required, acre	Cost ¢/1000 gal		
				Capital	O&M[b/]	Total
1	Land - 0.5 ft/day	477	40	9.3	5.6	14.9
1	Land - 1 ft/day	477	20	8.0	4.7	12.7
1	Activated sludge	608	1	23.7	16.1	39.8
10	Land - 0.5 ft/day	4,772	150	3.7	4.4	8.1
10	Land - 1 ft/day	4,772	90	2.6	3.3	5.9
10	Activated sludge	5,865	5	6.5	5.8	12.3
100	Land - 0.5 ft/day	47,727	1300	3.3	2.9	6.2
100	Land - 1 ft/day	47,727	700	1.7	2.6	4.3
100	Activated sludge	57,065	30	4.6	2.3	6.9

a/ Average daily infiltration rates of 0.5 and 1.0 ft/day represent total annual infiltration rates of 90- and 180 ft, respectively, when flooded 50% of the time.

b/ Operation and maintenance cost.

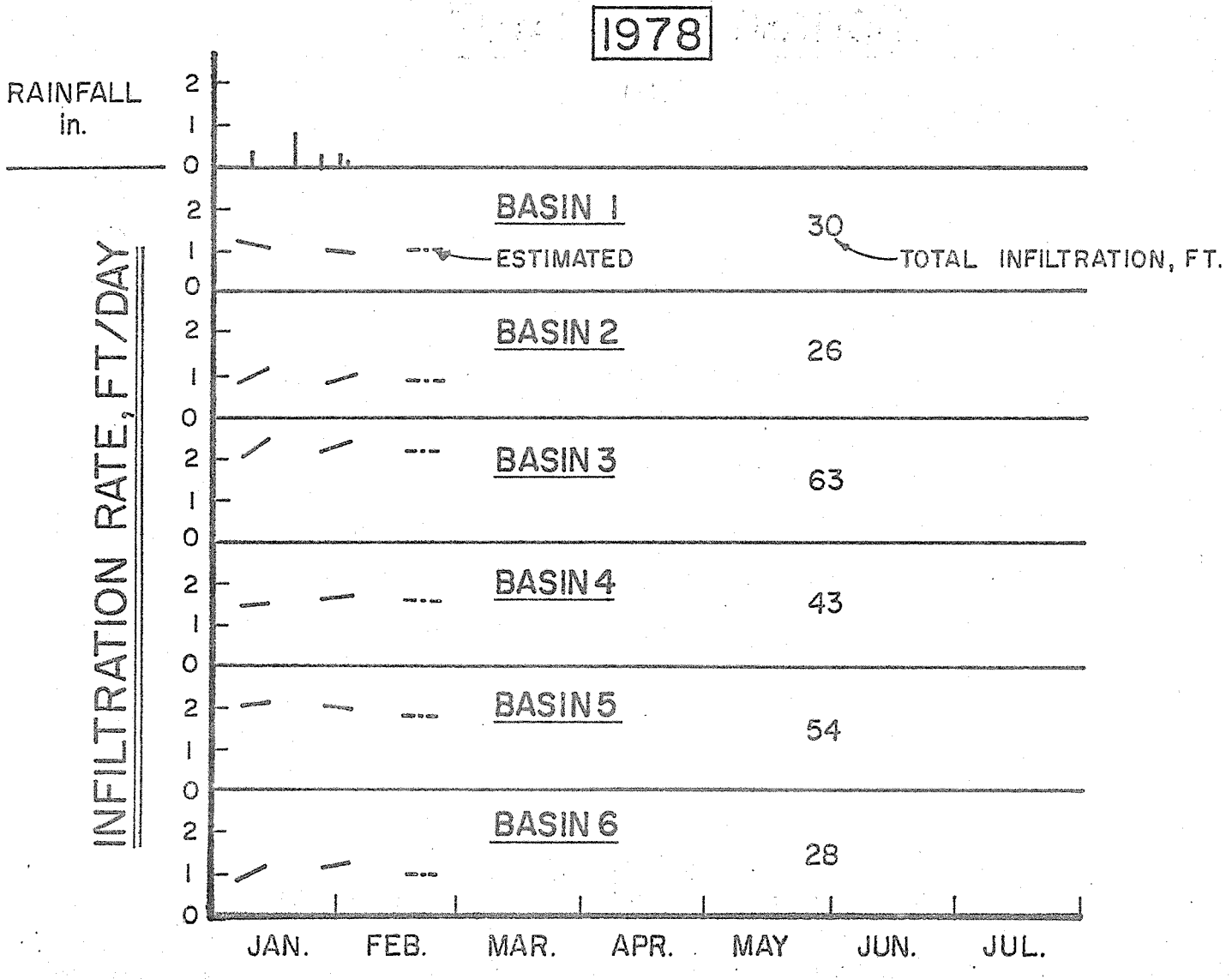

Figure 1. Infiltration rates, accumulated infiltration, and rainfall for the Flushing Meadows Project in 1978.

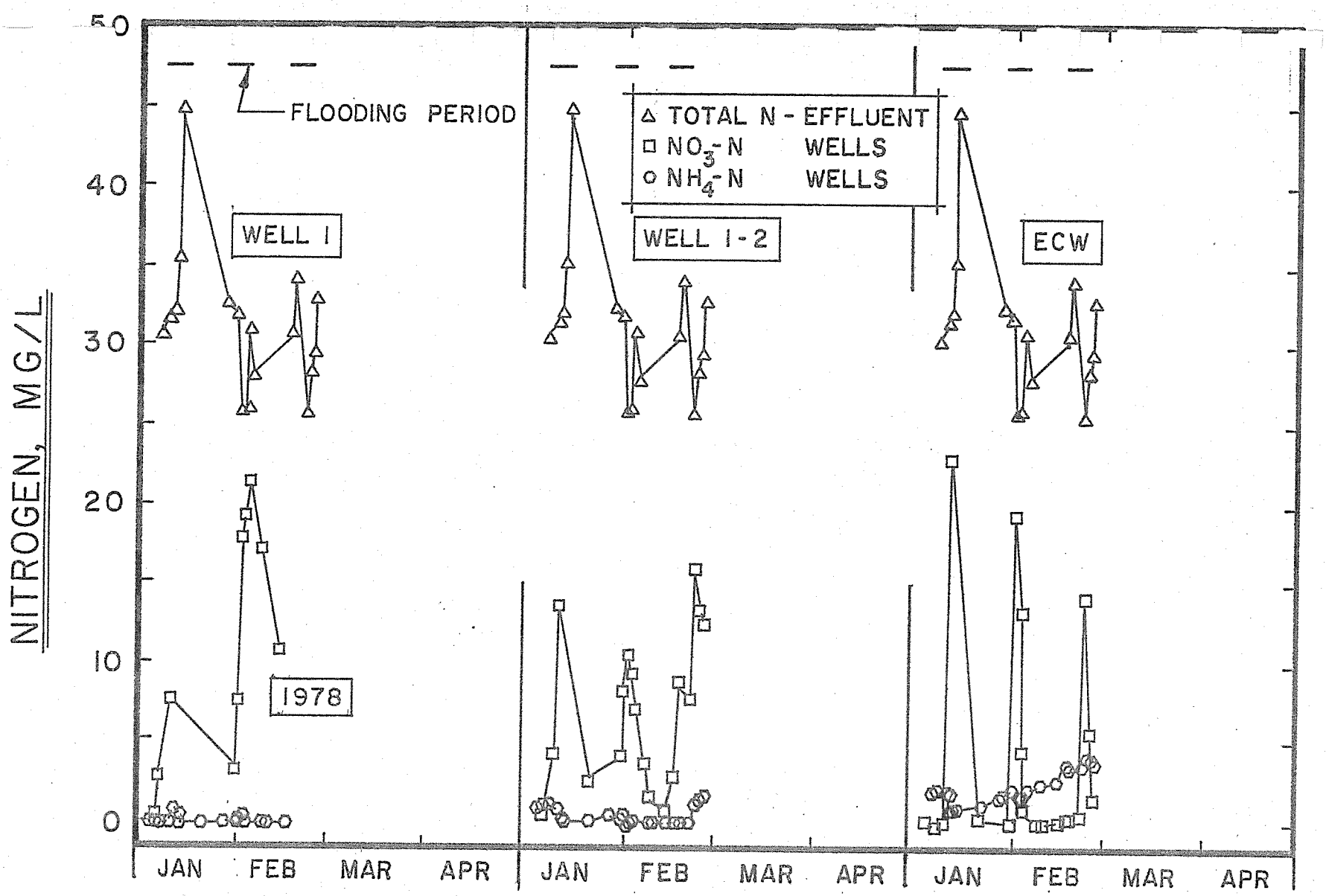

Figure 2. Concentrations of total-N in secondary effluent and NO_3-N and NH_4-N in renovated water from wells 1, 1-2, and ECW at Flushing Meadows Project.

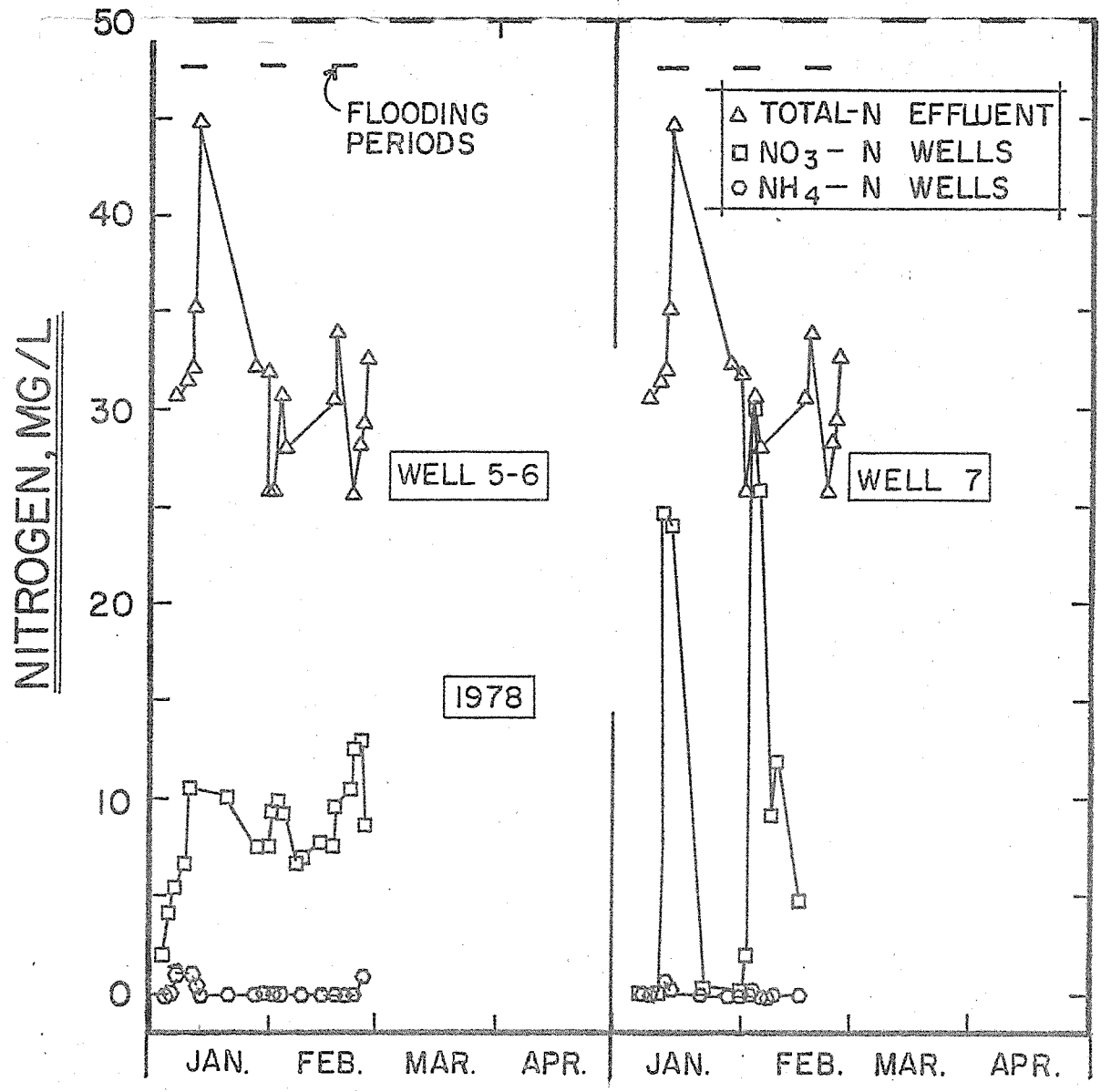

Figure 3. As in Figure 2, but for wells 5-6 and 7.

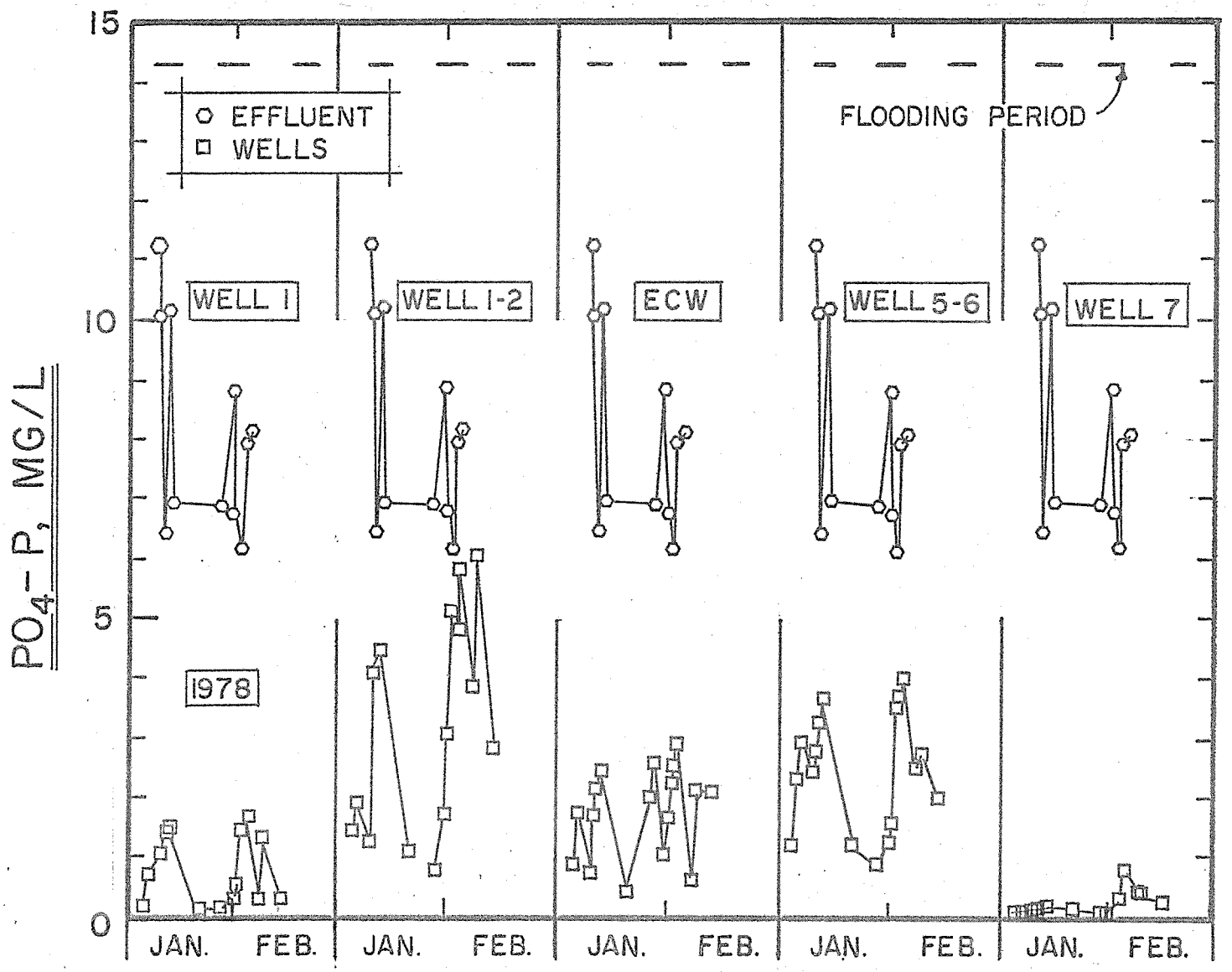

Figure 4. PO_4-P concentrations in secondary effluent and renovated water from the wells at the Flushing Meadows Project.

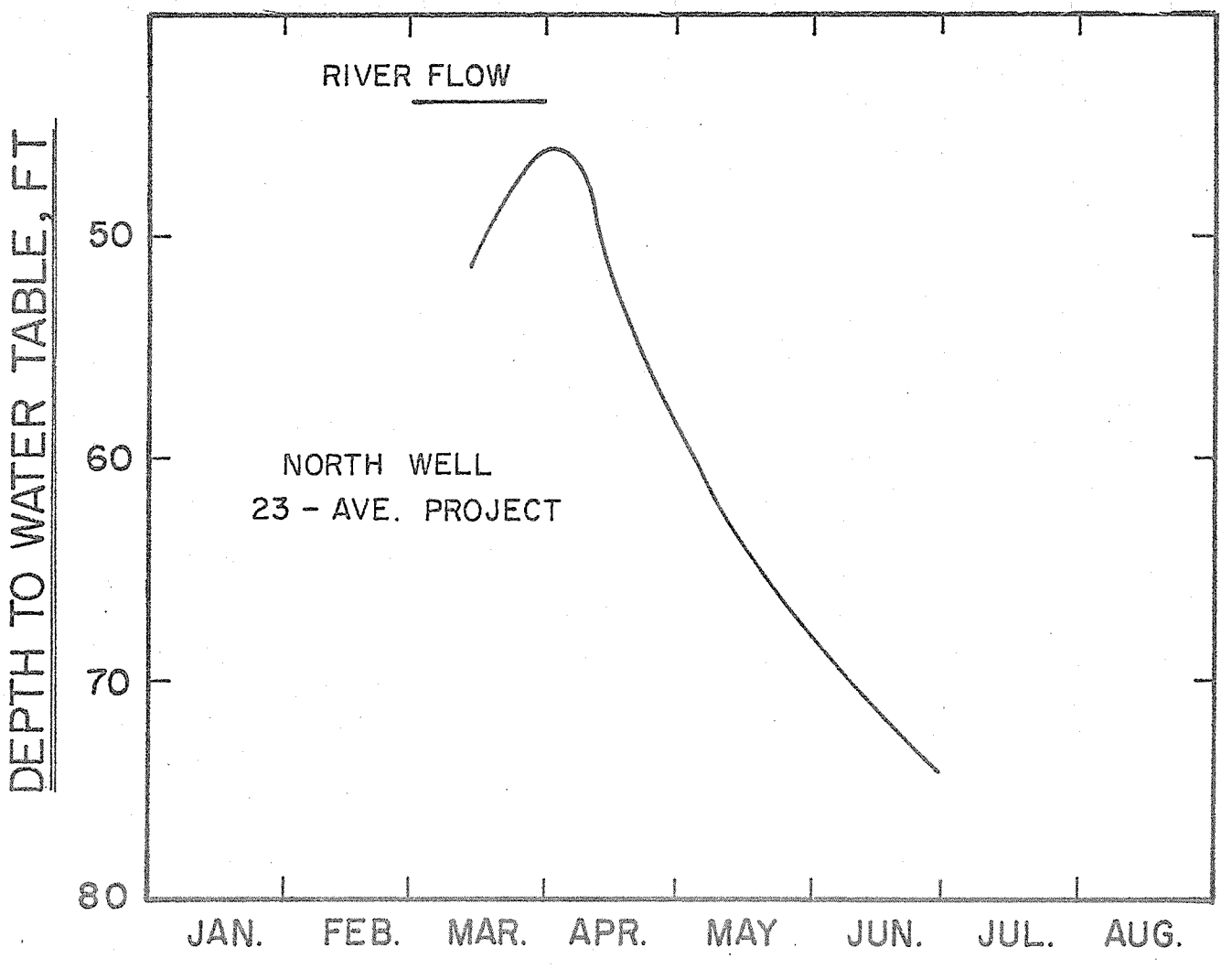

Figure 5. Water-table depths in the north observation well of the 23rd Avenue recharge project, showing response of well to seepage from Salt River.

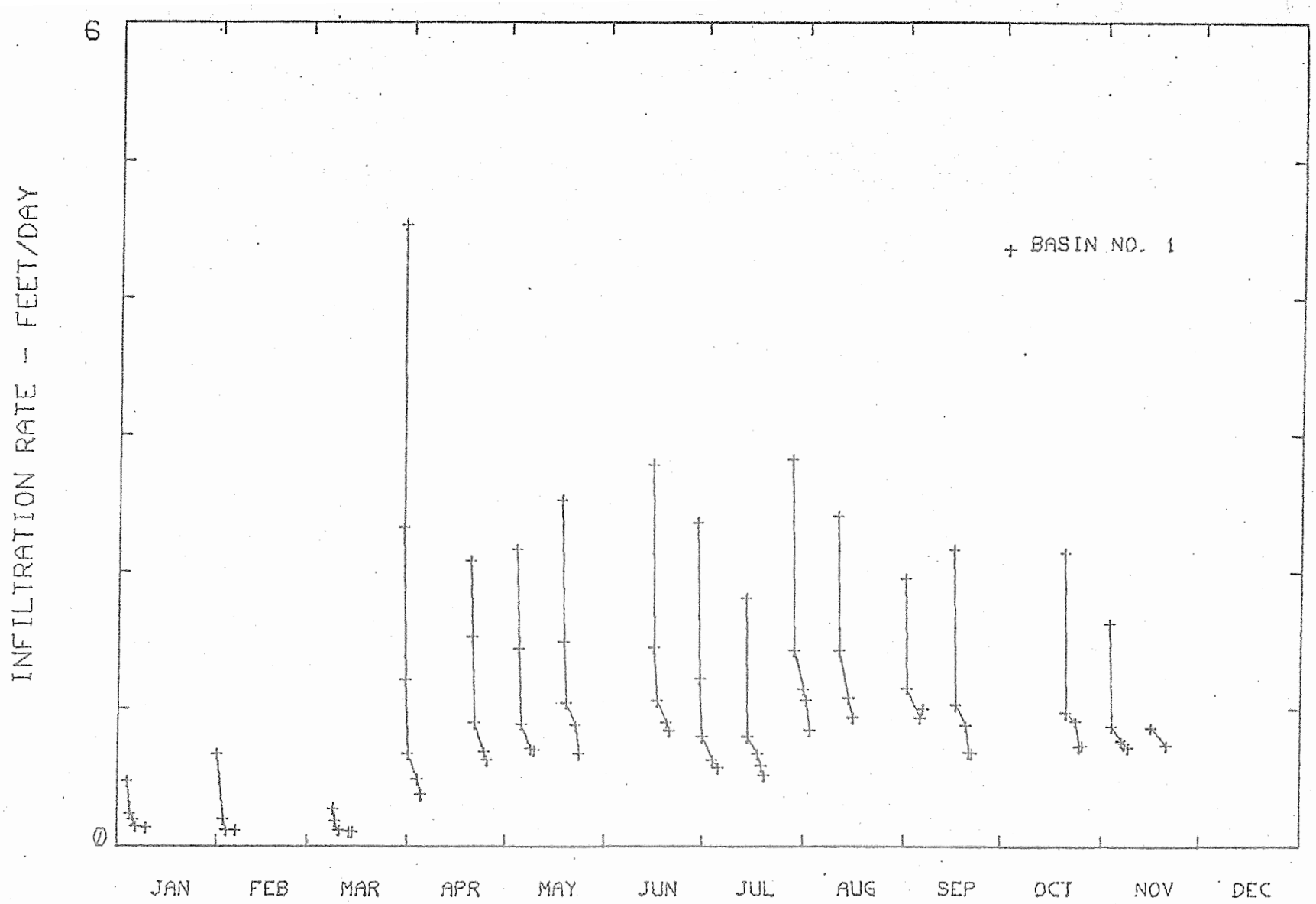

Figure 6. Infiltration rates in basin 1 of Mesa Primary Project.

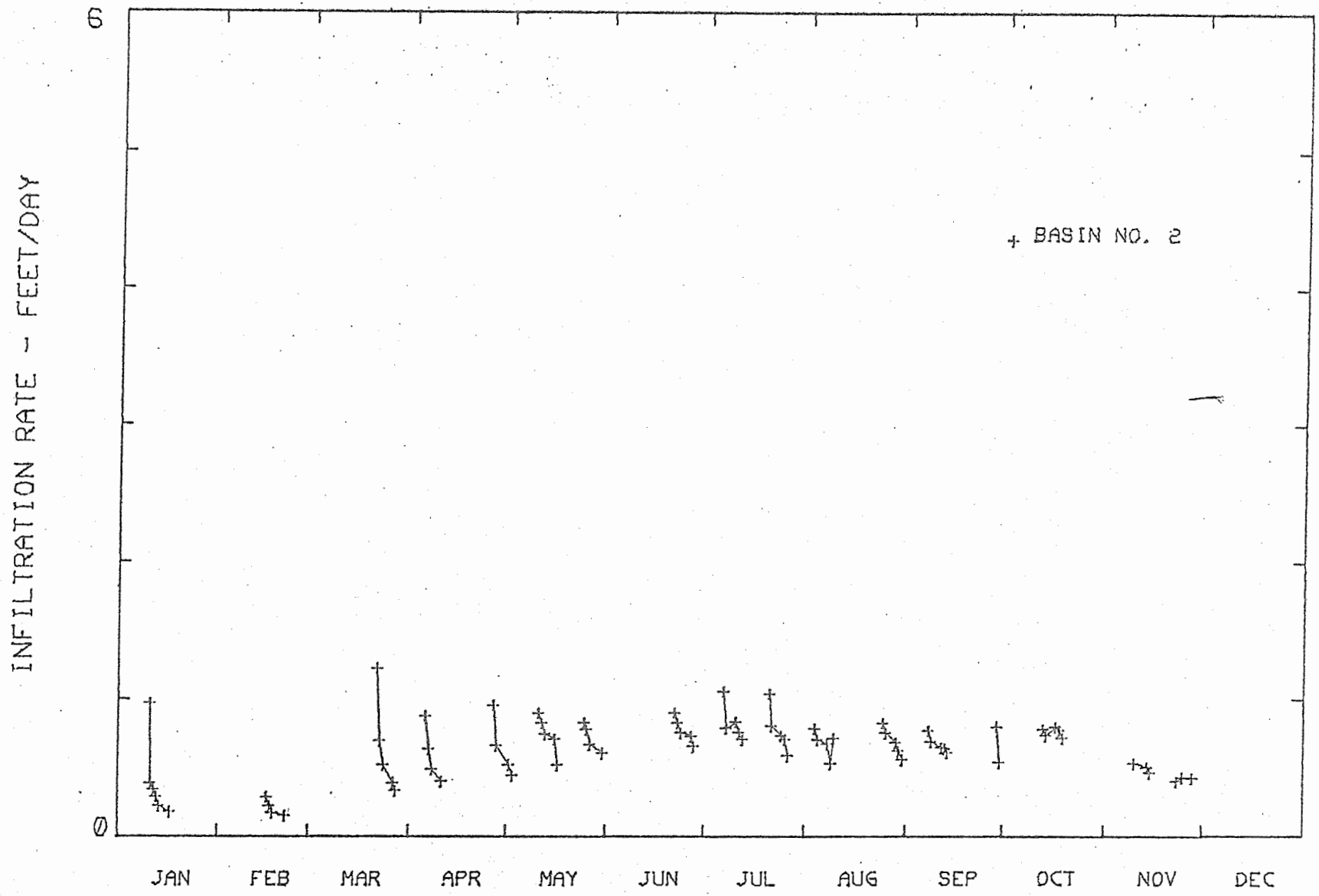

Figure 7. Infiltration rates in basin 2 of Mesa Primary Project.

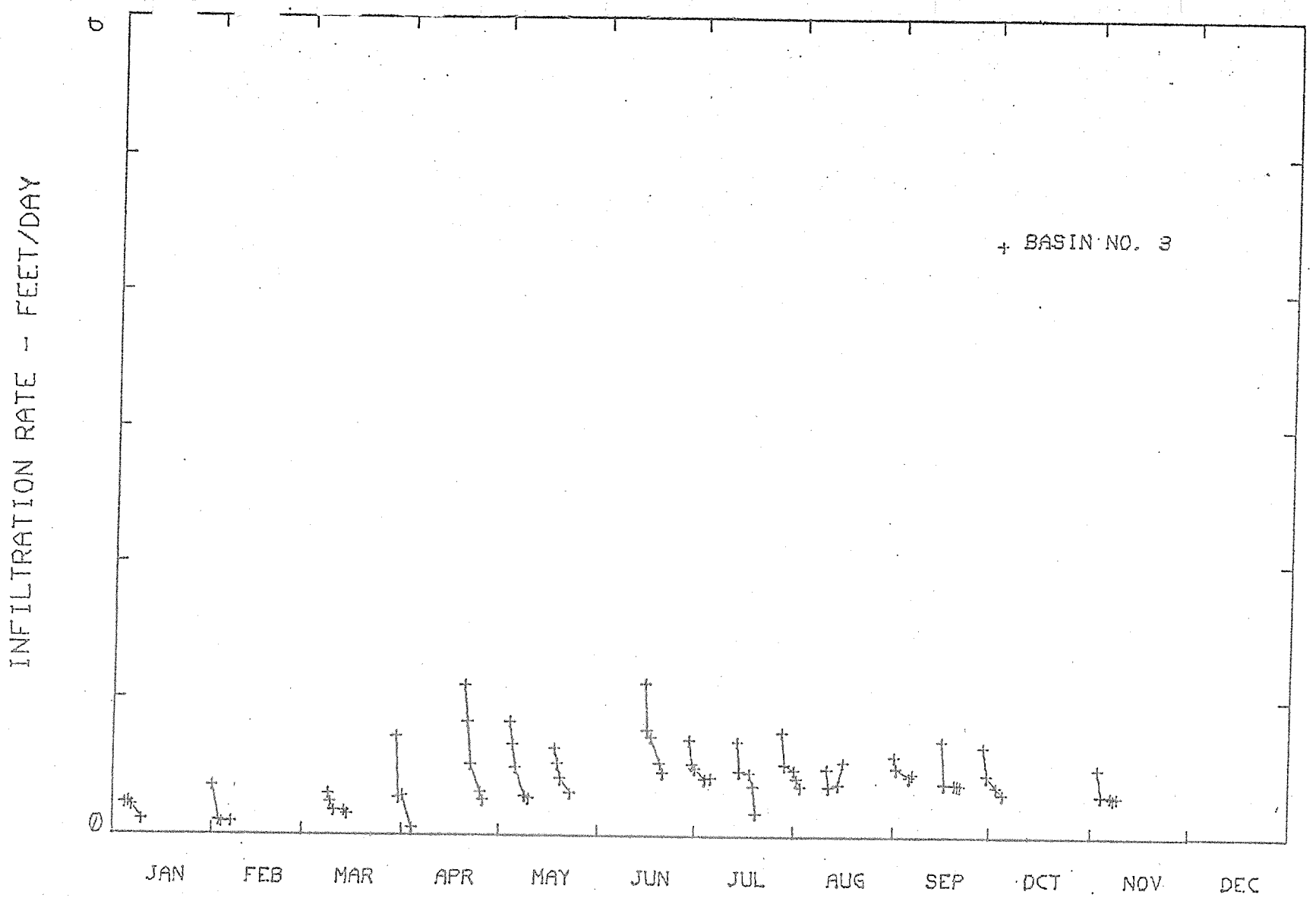

Figure 8. Infiltration rates in basin 3 of Mesa Primary Project.

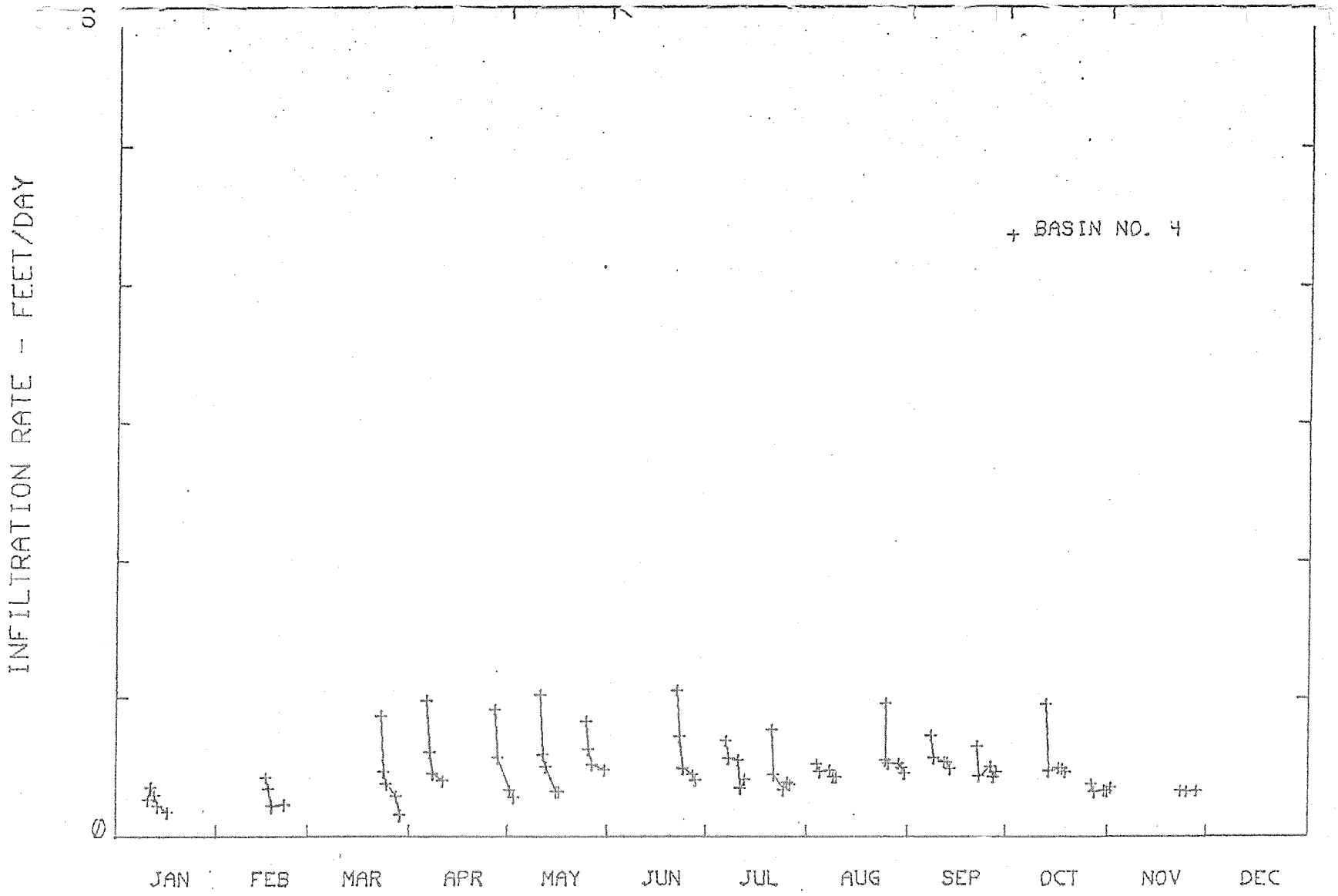

Figure 9. Infiltration rates in basin 4 of Mesa Primary Project.

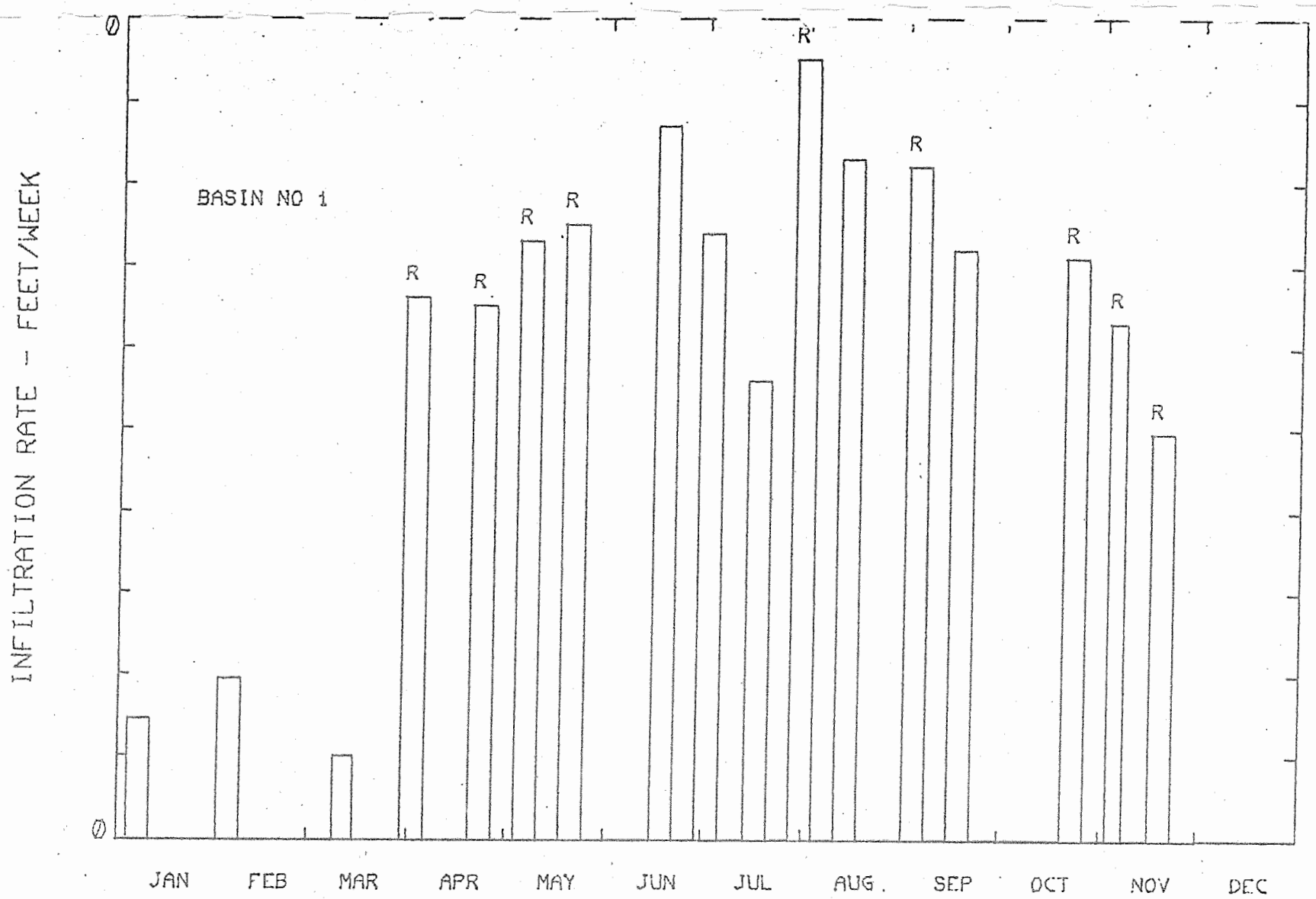

Figure 10. Weekly infiltration in basin 1 of Mesa Primary Project. Raking schedule is indicated by R.

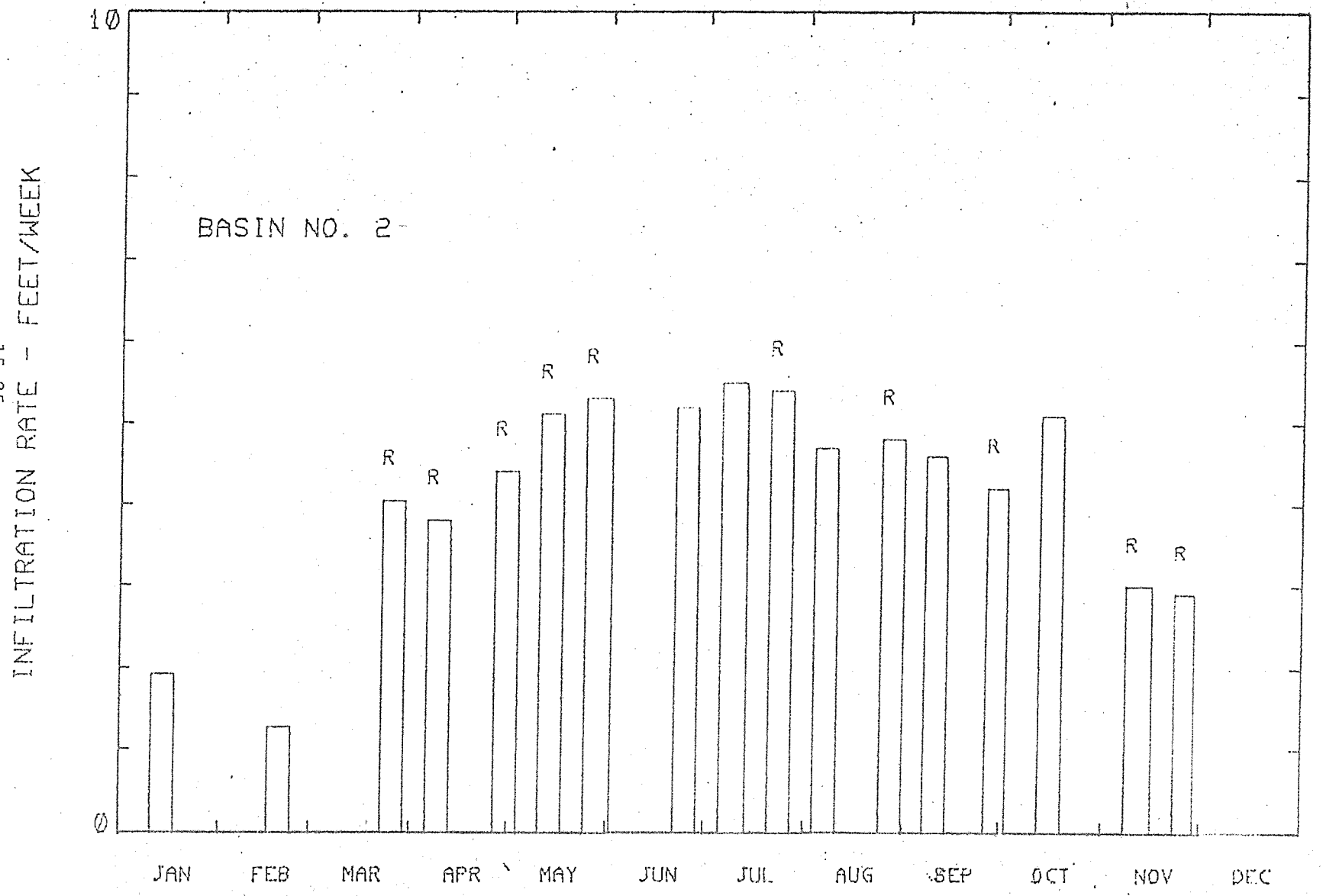

Figure 11. Weekly infiltration in basin 2 of Mesa Primary Project. Raking schedule is indicated by R.

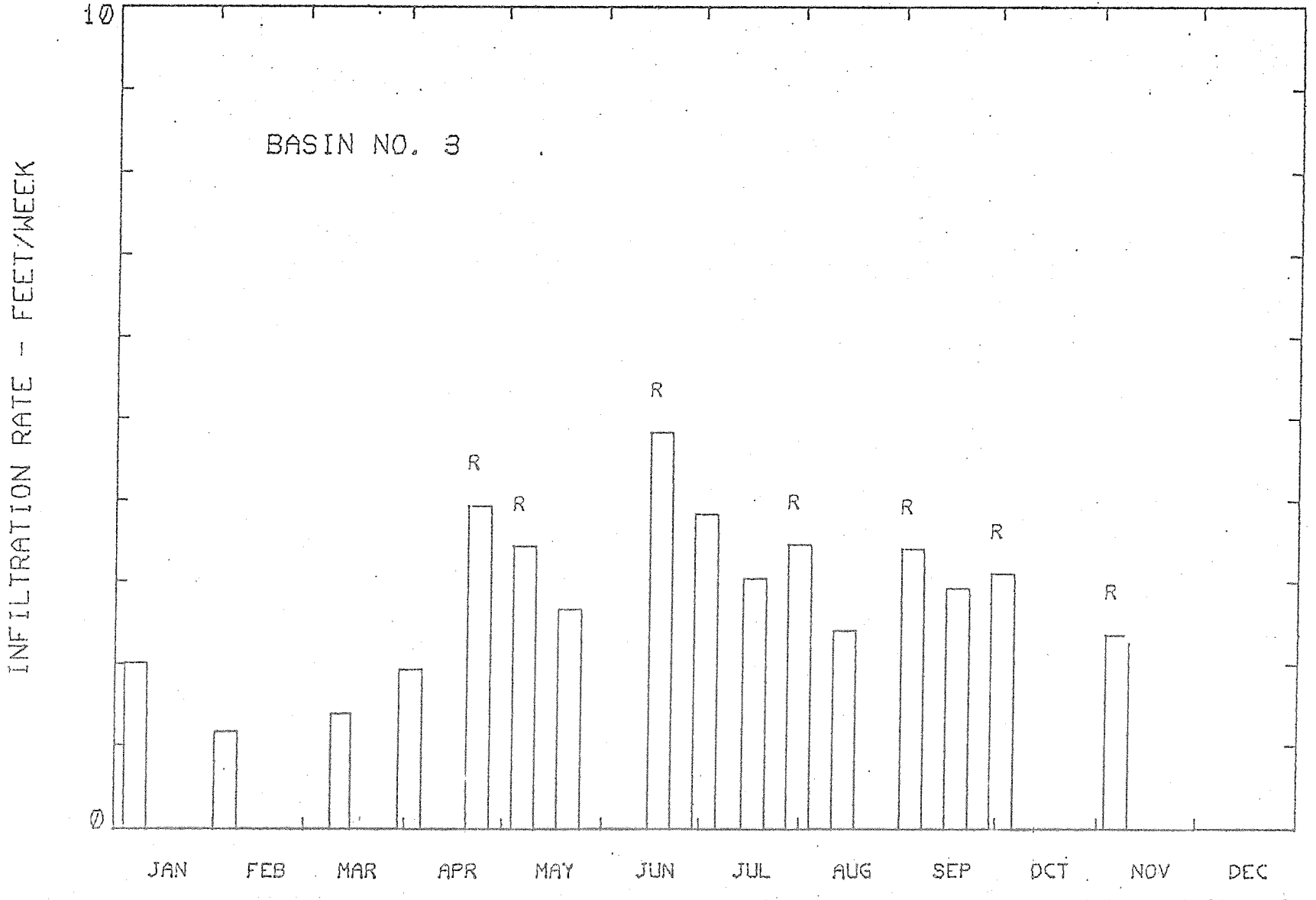

Figure 12. Weekly infiltration in basin 3 of Mesa Primary Project. Raking schedule is indicated by R.

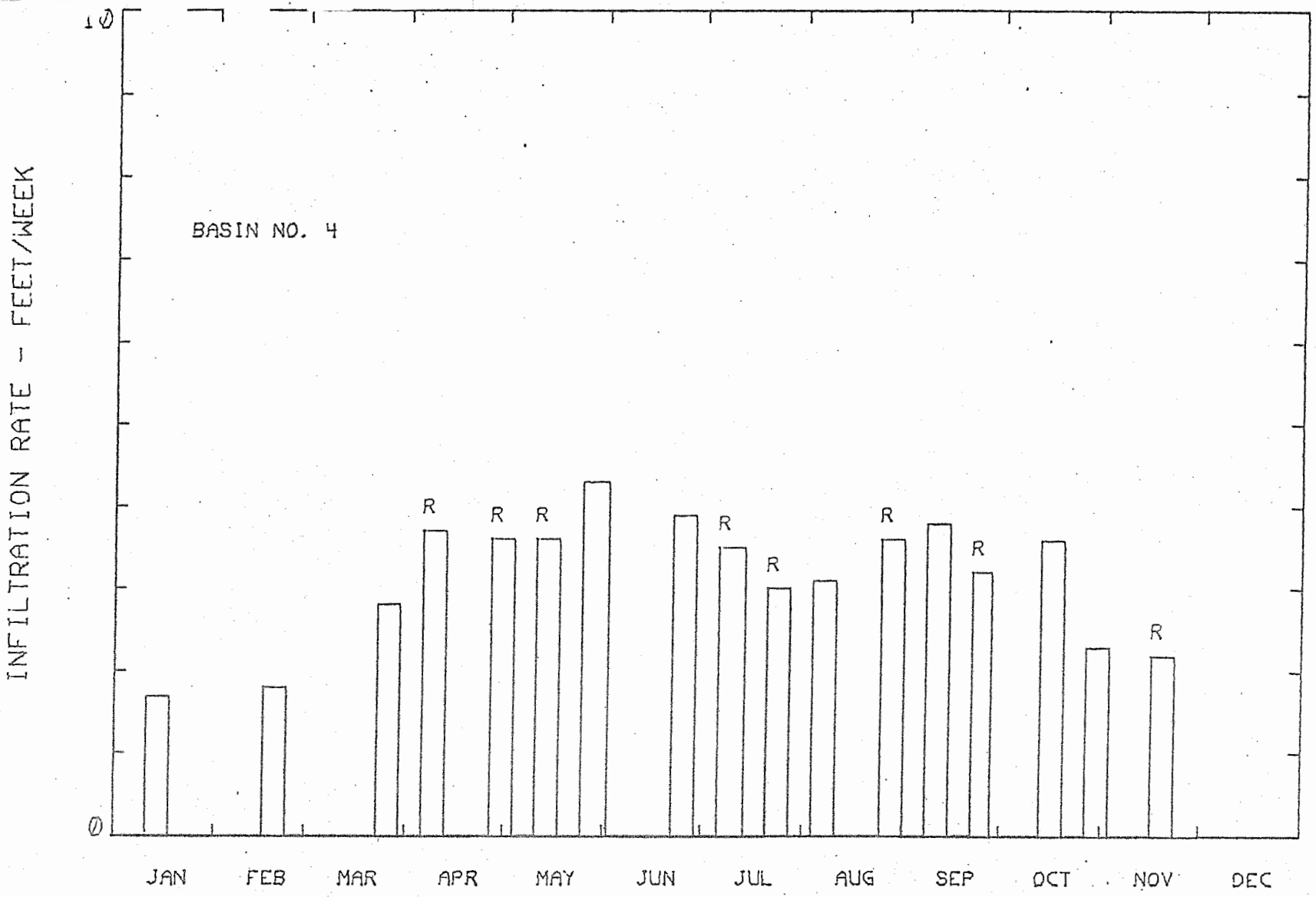

Figure 13. Weekly infiltration in basin 4 of Mesa Primary Project. Raking schedule is indicated by R.

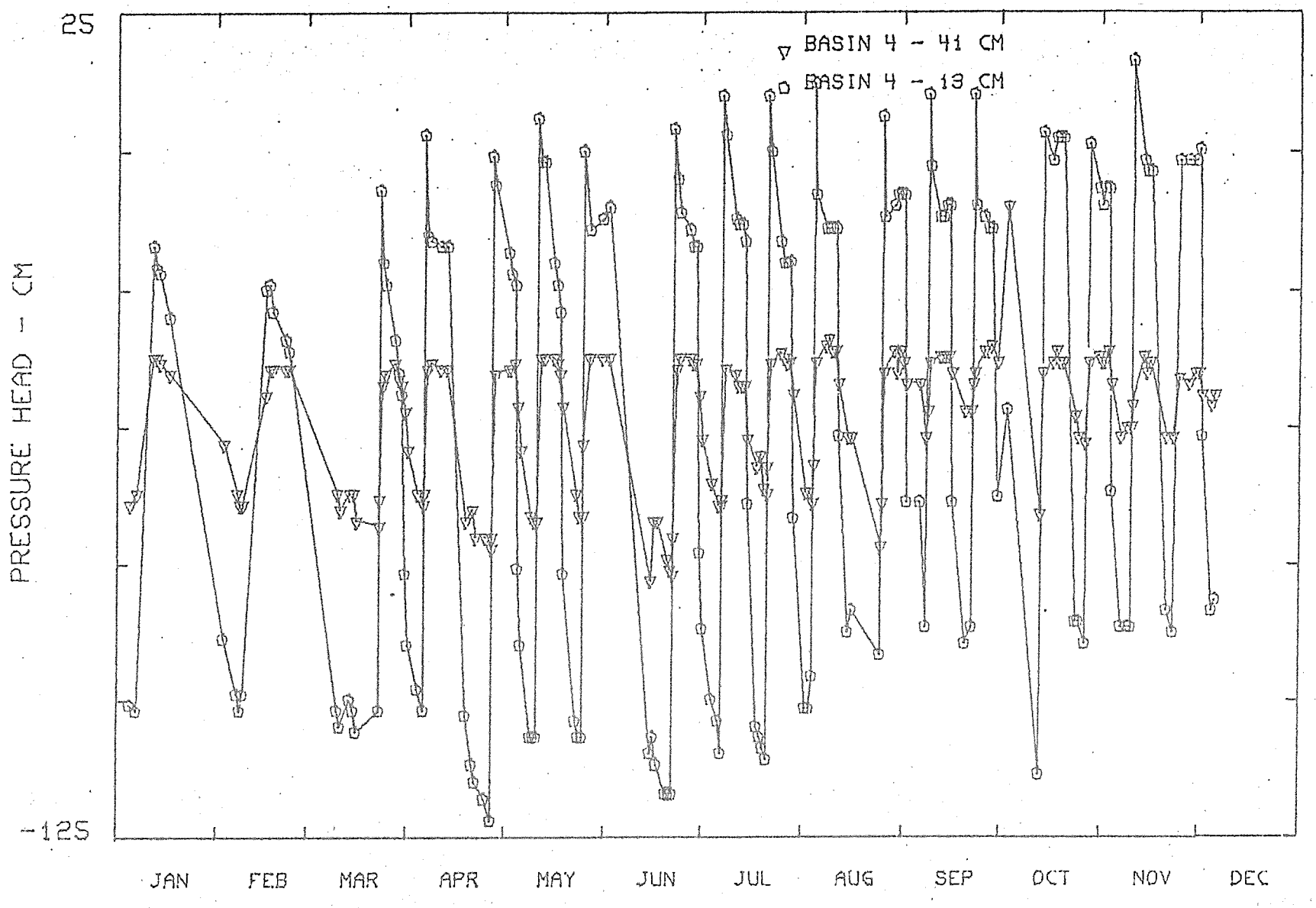

Figure 14. Pressure heads at two depths in basin 4 of Mesa Primary Project.

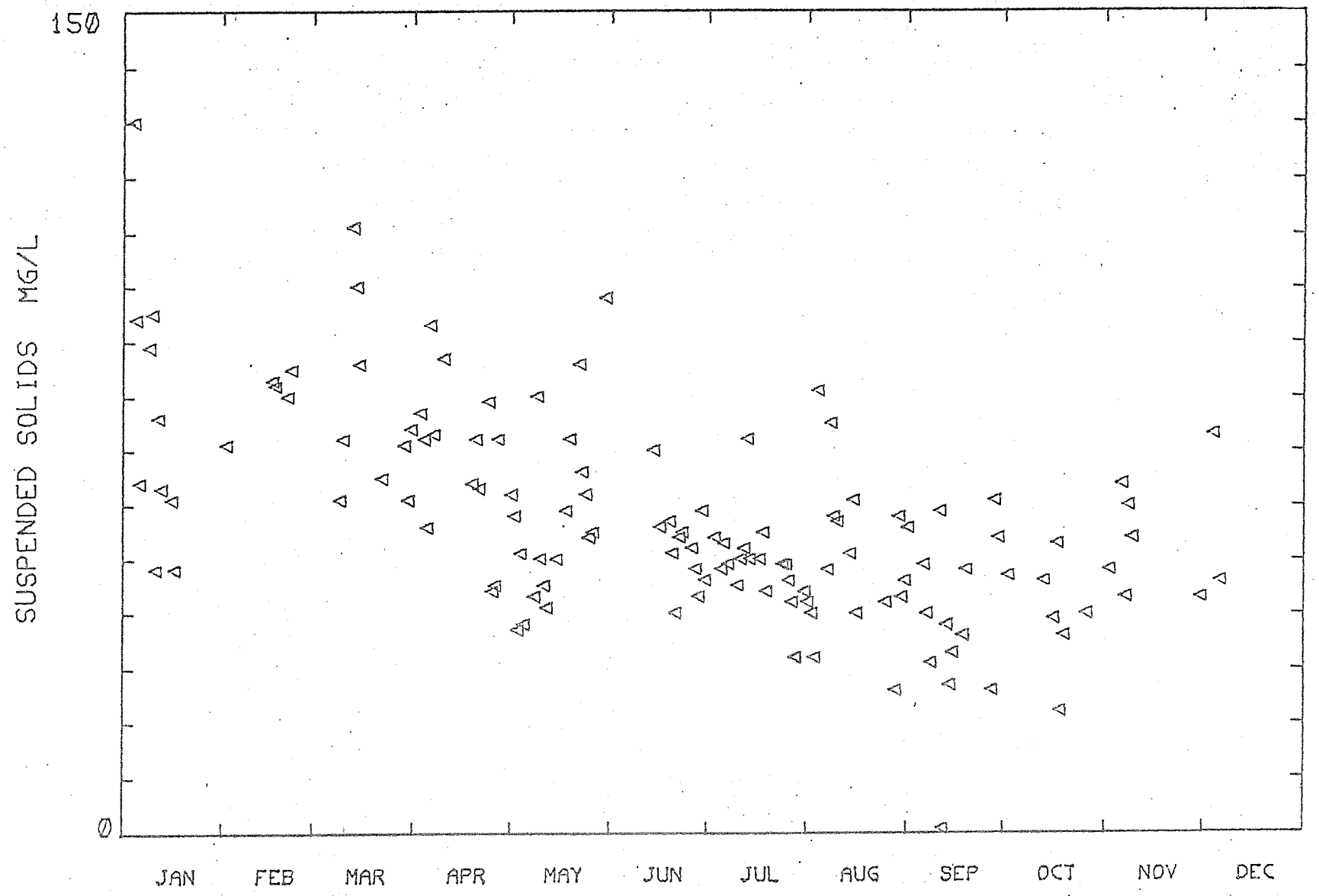

Figure 15. Suspended solids content of primary effluent.

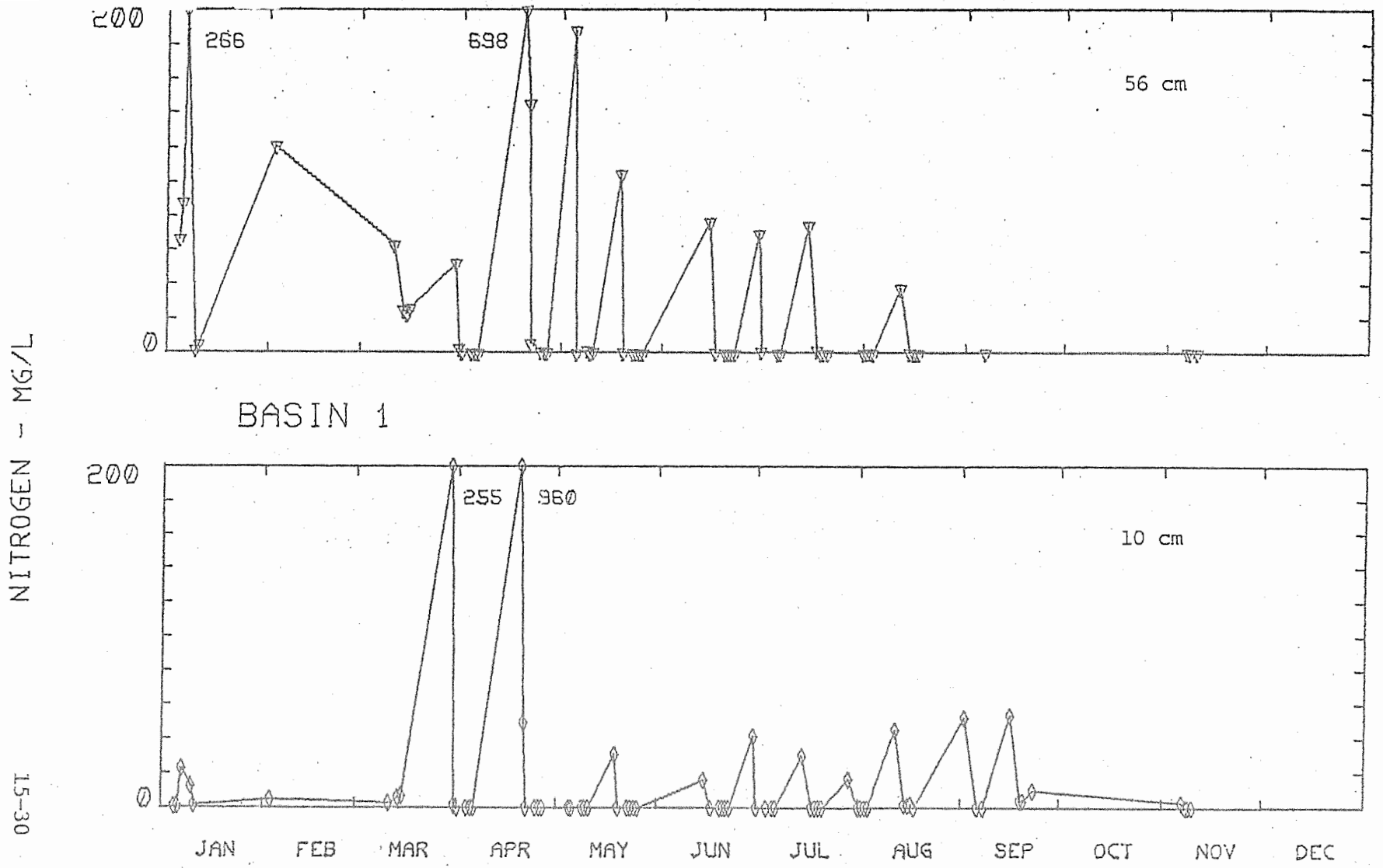

Figure 16. Nitrate nitrogen of soil solutions at two depths in basin 1 of Mesa Primary Project. Numbers indicate off-scale concentration.

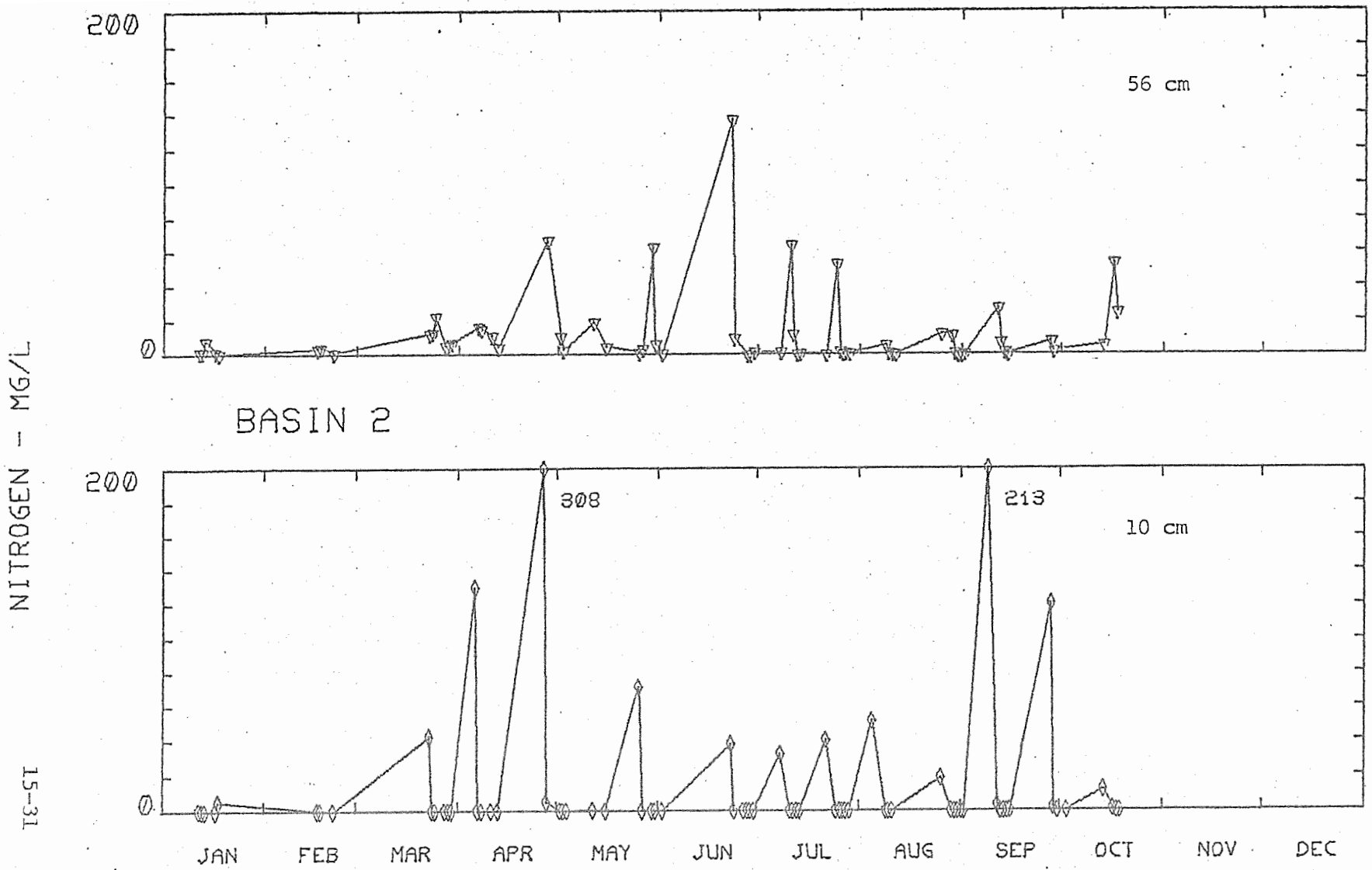

Figure 17. Nitrate nitrogen of soil solution at two depths in basin 2 of Mesa Primary Project. Numbers indicate off-scale concentration.

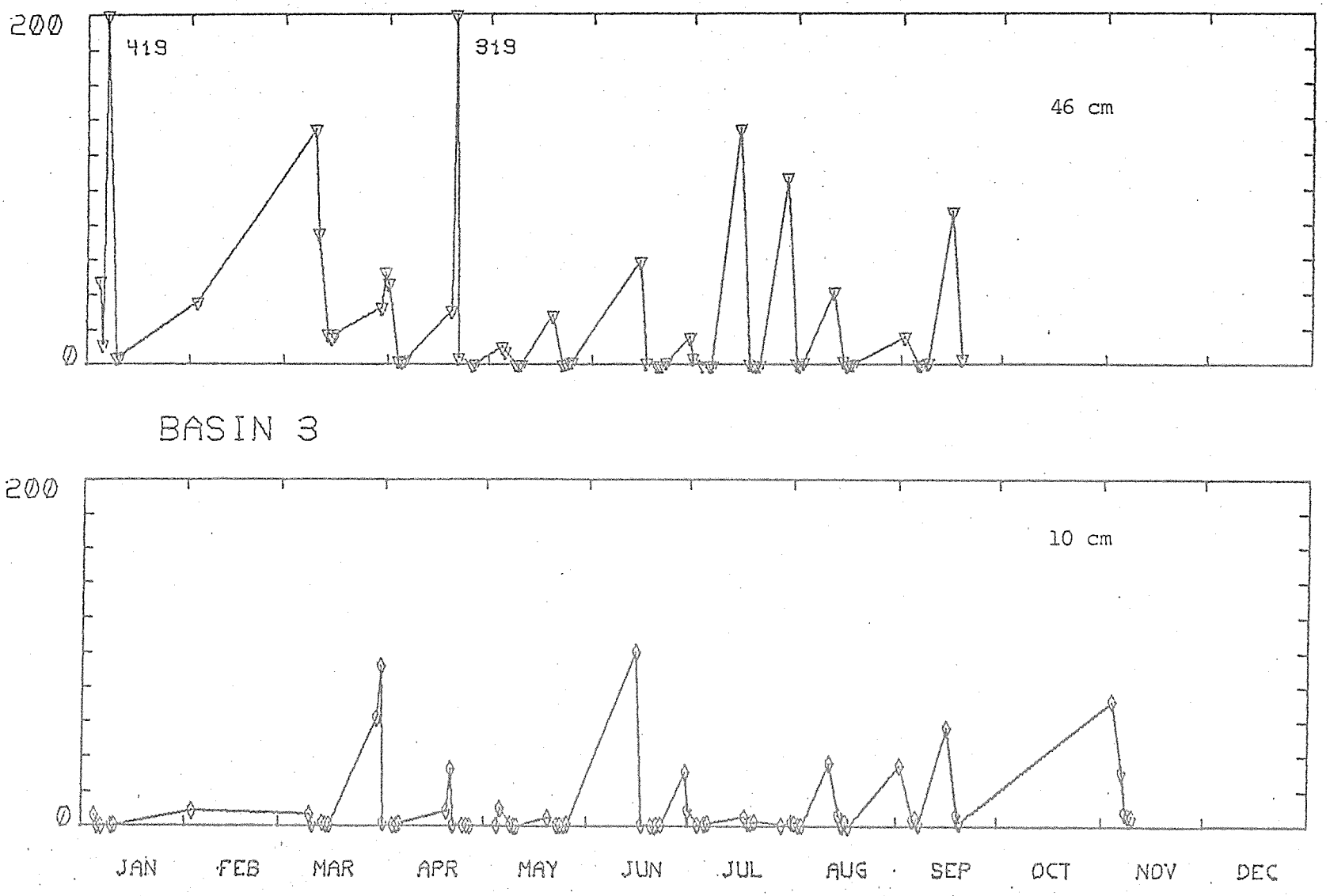

Figure 18. Nitrate nitrogen of soil solution at two depths in basin 3 of Mesa Primary Project. Numbers indicate off-scale concentration.

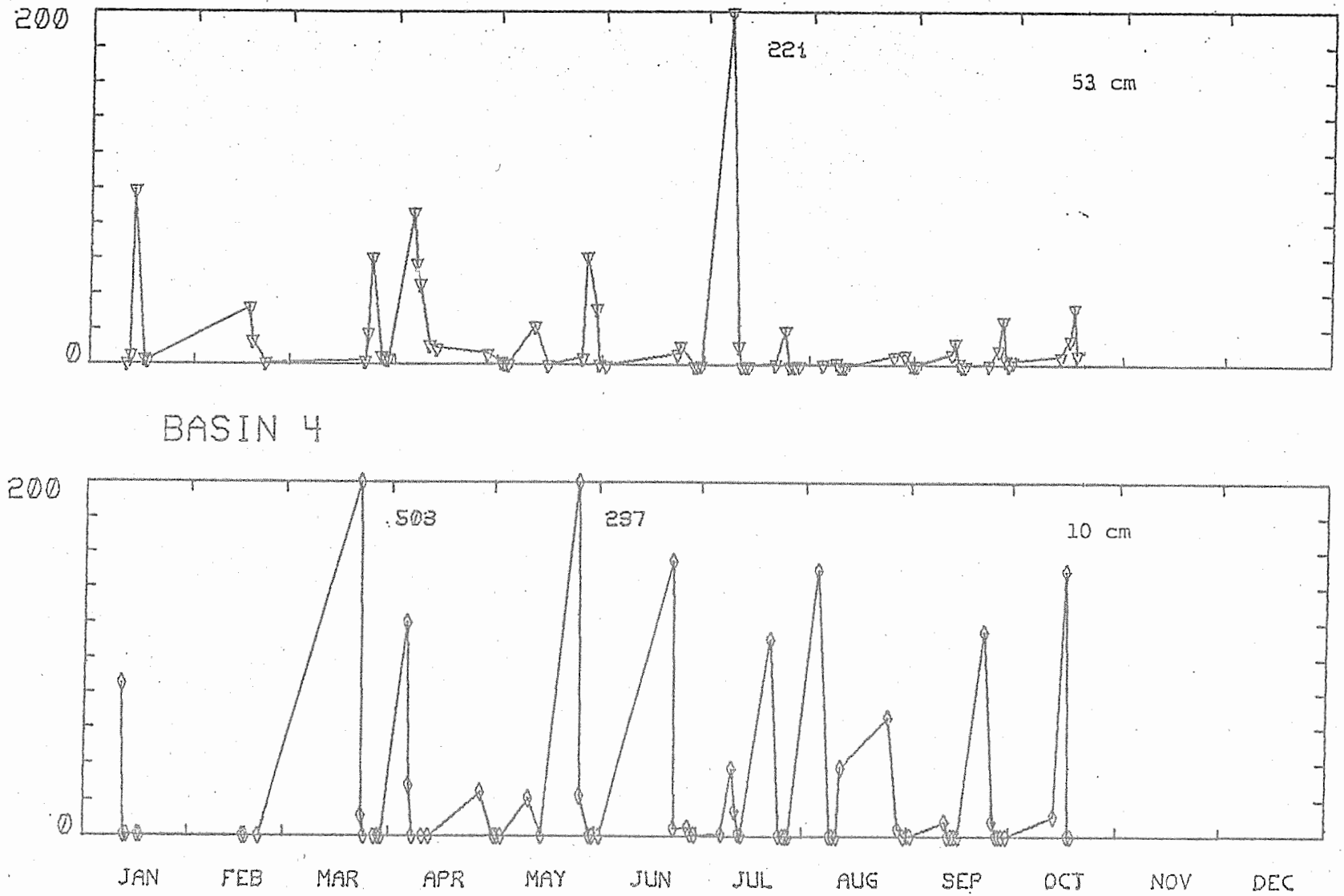

Figure 19. Nitrate nitrogen of soil solution at two depths in basin 4 of Mesa Primary Project. Numbers indicate off-scale concentration.

TITLE: COLUMN STUDIES OF THE CHEMICAL, PHYSICAL, AND BIOLOGICAL PROCESSES OF WASTEWATER RENOVATION BY PERCOLATION THROUGH SOIL.

NRP: 20790 CRIS WORK UNIT: 5510-20790-001

CODE NO.: Ariz.-WCL 68-3

INTRODUCTION:

Poliovirus (vaccine strain) has been used in many experiments to study virus movement and survival in soil and water systems. We have conducted experiments to determine if movement and survival of other viruses can be predicted from poliovirus studies. The experiments began with batch studies using small soil samples and a number of different virus types and strains in adsorption studies at Baylor College of Medicine. This has been followed up by studies on movement of Echo 1 and Echo 29, two viruses which showed low adsorption rates in batch studies.

Studies on nitrogen removal will focus on ways to remove nitrogen at high infiltrations rates. Phosphate studies have focused on stability of phosphates adsorbed by soils.

PROCEDURE:

Virus Studies. Soil columns filled with loomy sand were used in studies on movement of nitrogen, phosphate and viruses. Another column filled with coarse sand to allow high infiltration rates was used to study the effect of flow rate on virus adsorption.

A column which had been used previously to study the adsorption of poliovirus and echovirus, type 29 was flooded with sewage water containing 1.5×10^5 PFU/ml of echovirus type 1. Then the column was flooded at two day intervals with sewage water containing different concentrations of Echo 1. Finally the outlet device on the coarse sand column was adjusted to different heights to give different flow rates while the column was flooded with sewage water containing Echo 1.

In field studies, the survival of poliovirus and echovirus was studied at the Mesa plots which are flooded with primary effluent. PVC cylinders (10 cm ID and 30 cm long) were filled with sand from

the basins, seeded with virus and buried at different depths to study survival and downward migration of viruses. Plastic tubes (2 cm ID and 10 cm long) were also filled with sand and buried at various depths. Half of the tubes were capped and half were left open at both ends by uncapping and sawing off the tips of the tubes. The basin was flooded immediately after the tubes were buried. The basin was flooded for 5 days, dried for 5 days, and flooded again for 7 days. Tubes were extracted at various intervals during the dry periods and soil samples were frozen and shipped to the Baylor College of Medicine for virus assays. Soil samples were also taken from the basins for elusion of viruses adsorbed to the soil from the sewage water.

Two 1 m^2 basins near the Mesa recharge basins were constructed and flooded with primary effluent. Sewage water in 1 basin was seeded with 10^7 PFU poliovirus. Soil samples were taken at various intervals up to 30 days to compare survival of the added poliovirus and viruses naturally occuring in the sewage water applied to the control basin.

Four soil columns with different infiltration rates were flooded with sewage on a schedule of 8-9 days flooded and 5 days dry. The flooding periods were interrupted by brief drying periods (2-3 hours) during days 6, 7, and 8 to allow some nitrification during the flooding period. The column outflow was sampled daily and analyzed for NO_3-N, NO_2-N, NH_4-N and PO_4-P.

RESULTS AND DISCUSSION:

Virus Studies. When poliovirus type 1 and echovirus types 1 and 29 were added to secondary sewage effluent before the sewage water passed through 250 cm long soil columns, the adsorption patterns for Echo 29 and Polio 1 were similar with 90% adsorption in the top 2 cm and no viruses detected below 150 cm (Fig. 1). Adsorption of Echo 1 was 77% for the top 2 cm but the adsorption pattern was similar to patterns for the other two viruses below the 40 cm depth. The desorption and movement of polio and echo virus was similar when the columns were flooded with deionized water.

When a soil column was flooded with sewage water seeded with two different concentrations of Echo 1 virus (3.3×10^2 and 1.5×10^5-PFU/ml).

The percentage of the added virus remaining at the various depths was similar for both concentrations (Table 1). These results were similar to those obtained when a soil column was flooded with different concentrations of poliovirus.

When the column packed with coarse sand was flooded at different flow rates with sewage seeded with Echo 1 virus by changing the height of the column outlet, viruses did not move below 160 cm when the flow rate was 0.6 cm/day (Table 2). At flow rates of 1.2 and 2.4 meters/day, viruses broke through the soil column. This showed that Echo virus movement through the coarse sand column could be prevented by keeping the flow rate below 1.2 m/day. Again, the effect of flow rate on echo virus movement was quite similar to the effect of flow rate on poliovirus movement.

Therefore, the similarity of the adsorption patterns and of virus movement at different concentrations and flow rates indicates that poliovirus is a good model to use in studying the movement of echoviruses through soils. Since Echo 1 showed more variability than any other types of strains when adsorption of 38 types and strains was compared in batch studies with small soil samples, its similarity to Polio 1 in batch column studies indicates that Polio 1 is a good model to use in studying the movement of different enteroviruses through soils.

The assay of field samples from the virus survival studies has not been completed.

Nitrogen Studies. The infiltration rates for the soil columns used in testing the effect of short dry periods on denitrification are shown in Table 3. The experiments and data analysis have not been completed yet.

Phosphate Studies. Phosphate concentrations from columns flooded with sewage water after lengthy dry periods (6-18 months) were higher than the PO_4-P concentrations in the sewage (Fig. 2). The PO_4-P concentration in the column outflow seemed to be proportional to the length of drying time.

Table 1. Effect of Echo 1 virus concentration on movement through a soil column.

Depth cm	Added Virus Concentration 3.3×10^2	(PFU/ml) 1.5×10^5
	Per Cent Virus Remaining *	
2	42	33
5	22	28
10	15	25
20	9	12
40	12	2
80	4	0.2
160	0	0.02
240	0	0
250	0	0

* Data are averages of samples taken on 4 flooding days.

Table 2. Effect of infiltration rate on virus movement.

Column Depth cm	Flow rate m/day 0.6	1.2	2.4
	Virus Remaining PFU/ml		
0	1250	1250	1125
2	250	200	260
5	300	375	520
10	450	550	410
20	360	150	390
40	270	215	180
80	360	195	170
160	5	90	180
240	0	15	5
250	0	10	35
250a*	0	19	0

* 100 ml samples of column outflow.

Table 3. Infiltration rates of soil columns used for nitrogen studies.

Date 1978	Column 2	Column 3	Column 4	Column 8
16 Nov	74.67	116.28		64.25
17 Nov	105.2	110.13	28.11	85.93
18 Nov	116.07	102.02	113.31	72.79
20 Nov	108.53	86.38	95.76	67.44
21 Nov	54.76	23.35	68.3	67.48
22 Nov	53.65	28.86	69.95	47.22
24 Nov	56.39	31.19	74.61	59.19
28 Nov	35.98	6.51	50.85	33.76
29 Nov	46.13	24.93	52.28	35.97
30 Nov	42.61	26.68	48.77	33.91
1 Dec	44.43	29.3	50.0	35.48
4 Dec	50.0	8.13	60.69	4.55
5 Dec	47.5	23.54	50.53	31.09
6 Dec	43.67	22.57	44.37	29.25
7 Dec	44.6	23.5	43.65	22.89
12 Dec	39.88	3.15	51.23	32.26
13 Dec	45.35	20.83	49.59	33.27
14 Dec	42.88	23.05	52.68	29.18
15 Dec	41.74	23.03	48.26	31.03
19 Dec	38.65	3.51	58.19	33.65
20 Dec	48.30	20.19	60.53	34.67
21 Dec	45.36	23.08	58.76	32.79
22 Dec	44.40	38.16	46.89	31.3
27 Dec	34.63	1.47	45.24	29.0
28 Dec	40.85	16.84	51.33	34.68
29 Dec	47.14	26.25	46.16	32.62

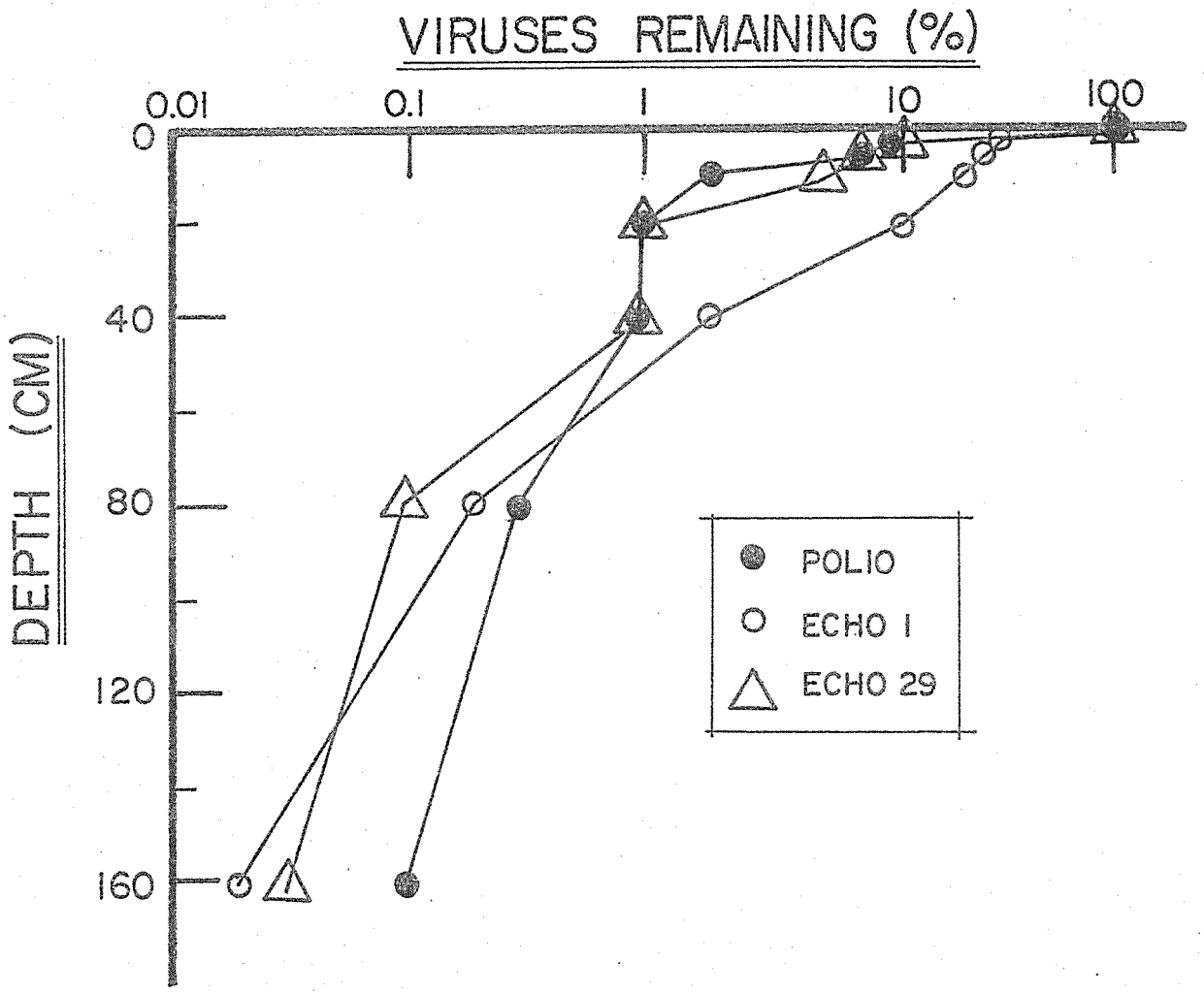

Figure 1. Viruses adsorption patterns in soil columns flooded with sewage water seeded with different viruses.

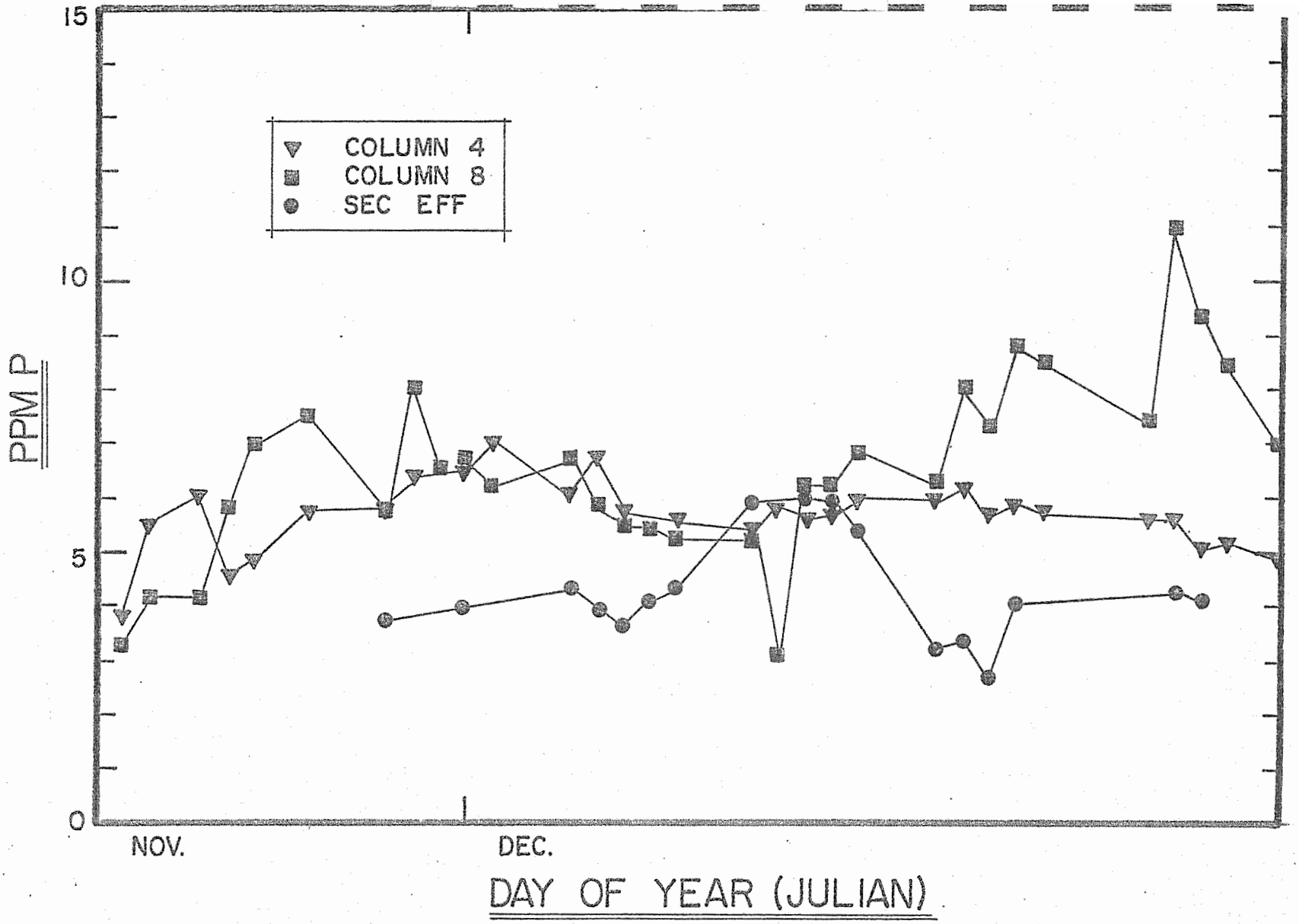

Figure 2. Phosphate concentrations in outflow from columns flooded with sewage water following extended drying periods.

TITLE: CHARACTERIZATION OF THE SOIL MICROFLORA AND BIOLOGICAL PROCESSES OCCURRING IN SOIL USED FOR WASTEWATER RENOVATION

NRP: 20790 CRIS WORK UNIT: 5510-20790-001

CODE NO.: Ariz.-WCL 70-2

INTRODUCTION:

During 1978, field investigations at the Flushing Meadows Project on the growth and activity of denitrifying bacteria in soil basins intermittently flooded with secondary sewage effluent (SSE) were terminated, because flood waters in the Salt River destroyed the project in March 1978. However, prior to this event, considerable important information on microbial aspects of wastewater renovation was obtained, especially for nitrogen transformation and nitrogen removal mechanisms in soil basins intermittently flooded with SSE. This report contains procedures and summary data from several experiments that determined the denitrifying potential during flooding and drying cycles in the soil system, as influenced by numbers of denitrifying bacteria, total organic carbon and depth in the soil profile. Other data from previous experiments will discuss the effect of algae on nitrification-denitrification processed during flooding cycles.

PROCEDURES:

Basin #1 at the Flushing Meadows Project was selected as the field site, because it has always been a bare soil basin that was flooded with SSE. Soil samples were collected and analyzed for water content, bacterial numbers, inorganic nitrogen and denitrification potential (Annual Report, 1977). Total organic carbon in soil profile samples from Basin #1 and the natural riverbed soil adjacent to the project were analyzed by wet combustion and gravimetric methods.

The effect of algae on nitrification and denitrification processes occurring during flooding periods was determined by measuring redox potentials, dissolved oxygen, temperatures and solar radiation with methods described by Gilbert and Rice (Publication, No. 4).

RESULTS AND DISCUSSION:

Denitrification Potentials. Biological denitrification is effected solely by bacteria and involves the reduction of nitrate or nitrite to gaseous forms of nitrogen, which are usually nitrous oxide and molecular nitrogen. With the proper environmental conditions, denitrification occurs rapidly in soil, because it is a respiratory process that utilizes nitrate as the terminal election acceptor in lieu of oxygen. Thus, denitrifying bacteria are essentially obligate aerobes, except for the ability to grow with nitrate in the absence of oxygen. They differ from the facultative anaerobic bacteria, which may reduce nitrate to nitrite only but no further, because they are unable to grow fermentatively by using organic compounds as electron acceptors. *Achromobacter* and *Pseudomonas* are the most common genera of denitrifying bacteria found in soil. Denitrification rates are increased by temperature, pH, nitrate concentration, organic carbon concentration and decreased by aeration. Consequently, denitrification quantitatively and qualitatively in soil basins intermittently flooded with SSE is strongly affected by wetting and drying cycles.

The influence of flooding and drying cycles on numbers of denitrifying bacteria, total organic carbon, and potential denitrification rates in the soil profile of a recharge basin flooded with SSE for 9 days and dried for 12 days are summarized in Tables 1 and 2. Denitrification potentials, as influenced by number of denitrifiers and total organic carbon, were greatest in surface (0-5 cm) of the soil basin and decrease with soil depth (Table 1) and were also greatest at the end of flooding and decreased during drying (Table 2). These results have defined the zones of denitrifying activity in the soil profile and the precise times when the denitrifying potentials are the greatest during the flooding and drying cycles. Therefore, management practices can be more effectively introduced at the pricise time and location that these biological activities can be controlled for enhancement of denitrification and nitrogen removal.

Denitrification and Total Organic Carbon. Analysis of total organic carbon in soil profile samples (0.90 cm) showed that the limited amount of organic carbon available for denitrification in SSE was deposited and accumulated in the surface soil (0.5 cm) during flooding and was mostly decomposed during drying (Tables 1, 2, 3). Also, refractory organics were not redeposited and concentrated at lower depths in the soil basin as compared with natural river bed soil profiles adjacent to the project (Table 3).

Nitrification-Denitrification and Algal Growth. Algal growth and oxygen evolution at the soil-water interface of soil recharge basins intermittently flooded with secondary sewage effluent (SSE) produced diurnal fluxes in dissolved oxygen (DO) in the SSE and redox potentials (Eh) in the SSE and the surface soil of the basin. The maximum daily DO-% saturation in the SSE during flooding ranged from 30 to 450% depending on the length of flooding and seasonal effects of temperature and solar radiation (Publication No. 3, Figure 1). Diurnal cycles of Eh in the SSE and the top 0 to 2 cm of soil indicated that oxygen production by algae and bacterial nitrifying and denitrifying reactions at the soil-water interface are occurring daily for limited periods during flooding (Publication No. 3, Figure 2) and that these reactions might contribute to the net-N removal and renovation of SSE by soil filtration. This nitrification-denitrification mechanism of nitrogen removal during flooding needs further study and confirmation.

SUMMARY AND CONCLUSIONS:

Field studies on denitrification and nitrogen transformations in soil basins intermittently flooded with secondary sewage effluent were terminated, because the research site (Flushing Meadows Project) was destroyed by flood waters in the Salt River in March 1978. However, the research that was completed prior to this time provided basic information about the growth and activity of nitrifying and denitrifying bacteria in the soil system used for renovation of secondary sewage effluent.

Nitrification-denitrification processes and nitrogen removal mechanisms in soil basins intermittently flooded with secondary

sewage effluent were determined to occur simultaneously at the start of each drying period within the same surface region or adjacent surface zones of the soil profile (0-5 cm). The potential for denitrification and numbers of nitrifying and denitrifying bacteria were greatest at the end of each flooding period and decreased during drying periods. During flooding, nitrification-denitrification processes were influenced by diurnal oxygen production from algae growing extensively on the soil surface. Analysis of total organic carbon in the soil profile indicated that one of the major factors limiting denitrification in the wastewater renovation system was organic carbon. These results have indicated that effective management of wastewater through nutrient additions, perhaps in the form of primary sewage effluent, at precisely when denitrification potentials are greatest would maximize nitrogen removal and reduce the nitrate pollution hazard of groundwater below high-rate land treatment systems.

PUBLICATIONS:

1. Smith, J. H., R. G. Gilbert and J. B. Miller. Redox potentials in a cropped potato processing wastewater disposal field with a deep water table. J. Environ. Qual. 7:571-574. 1978.

2. Gilbert, R. G., J. C. Lance, and J. B. Miller. Denitrifying bacteria populations and nitrogen removal in soil columns intermittently flooded with secondary sewage effluent. J. Environ. Qual. (In press).

3. Gilbert. R. G. Denitrification in soil recharge basins intermittently flooded with secondary sewage effluent. 70th Annual Meeting, Amer. Soc. Agron. and Soil Sci. Soc. Amer., Chicago, Ill. 3-8 December 1978. Agron. Abstr. p. 139.

4. Gilbert, R. G. and R. C. Rice. Effect of algal growth and dissolved oxygen on redox potentials in soil flooded with secondary sewage effluent. Hydrology and Water Resources in Arizona and the Southwest 8:132-136. 1978.

5. Rice, R. C. and R. G. Gilbert. Land treatment of primary sewage effluent: Water and energy conservation. Hydrology of Water Resources in Arizona and the Southwest 8:33-36. 1978.

PERSONNEL: R. G. Gilbert and J. B. Miller

Table 1. Numbers of denitrifying bacteria, total organic carbon, and potential denitrification rates in the soil profiles of a recharge basin flooded with secondary sewage effluent for 9 days and dried for 12 days.

Soil Depth	Denitrifiers/g		Total Organic Carbon		NO_3-N: Loss/day	
	End Flood	End Dry	End Flood	End Dry	End Flood	End Dry
(cm)	(x 10^6)	(x 10^6)	(%)	(%)	(µg N/g)	(µg N/g)
0-5	13.00	1.10	2.87	1.38	89	36
5-10	7.90	2.80	0.48	0.76	-	-
10-15	0.64	0.95	0.47	0.72	25	25
15-20	0.28	0.49	0.30	0.41	-	-
20-25	0.80	0.49	0.22	0.26	-	-
25-30	0.80	0.11	0.19	0.15	12	8
30.60	0.36	0.08	0.13	0.15	Trace	Trace
60.90	0.51	0.07	0.13	0.08	Trace	Trace

Table 2. Numbers of denitrifying bacteria, total organic carbon, and potential denitrification rates in the surface soil (0-5 cm) of a recharge basin flooded for 9 days with secondary sewage effluent and dried 12 days.

Condition of Soil Basin	Denitrifiers/g	Total Organic Carbon	NO_3-N: Loss/day
(Days: Flood/Dry)	(x 10^6)	(%)	(µg N/g)
12 dry	1.8	1.26	43
5 flood	8.2	1.46	71
9 flood	23.6	1.73	100
5 dry	2.1	1.55	51
12 dry	1.8	1.26	43

Table 3. Total organic carbon in soil profile samples from Basin No. 1 at the Flushing Meadows Project compared with natural river bed soil profiles adjacent to the project.

	Total Organic Carbon[1/]	
Soil Depth	Basin Soil	Natural Soil
(cm)	(%)	(%)
0-5	2.13	0.58
5-10	0.62	0.64
10-15	0.60	0.48
15-20	0.36	0.40
20-25	0.24	0.36
25-30	0.17	0.39
30-60	0.16	0.30
60-90	0.11	0.36

1/ Results are averages of data for two soil profile samples from each location.

TITLE: USE OF FLOATING MATERIALS TO REDUCE EVAPORATION FROM WATER SURFACES

NRP: 20810 CRIS WORK UNIT: 5510-20810-002

CODE NO.: Ariz.-WCL 71-6

INTRODUCTION:

Long-range durability and efficiency studies were continued at Granite Reef for four covers in 1978. Included were foamed rubber, foamed wax blocks, and two continuous wax covers on the 9-ft-diameter stock tanks. This project was scheduled for termination at the end of 1977; however, it was noted that the continuous wax covers were starting to sink, and it was decided that data would be collected for 1978 to see if the covers would recover as the hot summer temperatures heated the tanks. Visual observations of the performance of the wax cover on the lined pond also continued.

Field evaluation of the foamed rubber covers, the first located on a tank in 1971 in Southwestern Utah, and four others on tanks in Arizona in 1974, was continued. Information was obtained regarding performance of some 30 field operational covers located on tanks on the Arizona Strip and near Safford, Arizona.

A final report and paper will now be completed on this project.

PROCEDURE:

Evaluation of the four covers on the Granite Reef tanks was the same as in previous years (evaporation from a treated tank being compared to that from an identical untreated tank).

Only visual observations of the field-installed foam rubber covers were made. Evaporation measurements were not recorded.

RESULTS AND DISCUSSION:

Granite Reef Studies: The 1978 data indicate that the efficiency of the foamed wax blocks remained the same (32%) as in the previous 8 years of exposure on the Granite Reef stock tanks. Efficiency of the foamed rubber cover was 86%, which was also essentially the same as in the previous 4 years of exposure. The two continuous wax covers which appeared to start failing last year had even lower

efficiencies in 1978. Efficiency for the 120°-125° melting point wax cover had averaged near 87% the first 5-1/2 years, but had decreased to 75% in 1977, and averaged only 47% in 1978. The efficiency of the 128° melting point wax cover also averaged near 87% for 4-1/2 years, but decreased to 78% in 1977, and averaged only 68% in 1978. Both of these covers were much slower to respond to the hot summer temperatures than in the past, and both were noted to be partially submerged much of the year. Whatever the reason for the decreased efficiency, it is apparent that both covers are failing after 5 to 6 years exposure.

The wax cover on the lined pond at Granite Reef still covers about 80% of the surface and appears to be in good condition.

Field Studies: Five experimental foamed rubber covers continued to be observed during 1978. Functional operation reports of each follow:

Beaver Dam Tank, southwest of St. George, Utah, installed November 1971. The tank is still actively being used and the cover is still in excellent condition.

Frasier Well Tank, Hualapi Indian Reservation, installed May 1974. The cover continues to function satisfactority without change.

Shipley Well Tank, Hualapai Indian Reservation, installed May 1974. The cover was reported to have a 25-ft tear. Cover had partially floated off the tank when the tank overflowed. It also, while partially off the tank, froze into place. The tearing occurred when in this position. Plans are under way to patch the tear and return the cover to the tank.

Glover Ranch Tank, south of Safford, Arizona (Bureau of Land Management), installed September 1974. The cover is still used and operation is satisfactory. The BLM District constructed 15 foamed rubber covers for controlling evaporation from tanks used to store water from various water harvesting catchments on the District. More covers will be constructed

during 1979. Tank diameters range from 25 to 30 ft.

Hughes Ranch Tank, south of Rye, Arizona (Tonto National Forest), installed November 1974. The cover is in excellent condition. It floated off the tank once during the year, but stops were installed on the tank to prevent recurrence. The catchment and storage tank are providing a continual water supply for the livestock.

The Bureau of Land Management on the Arizona Strip has installed 15 covers on tanks over the past three years. Operation has generally been satisfactory. In a few instances some shrinkage has occurred, but the problem does not seem to be uniform for all covers. One cover was destroyed by what appears to be bird pecking--likely crows. Some pecking was noted on one of the first covers tested in 1971 (Jackson Wash Tank, near Cedar City, Utah), but the damage was limited. The cover was still functional.

SUMMARY AND CONCLUSIONS:

The evaporation reduction efficiency of the foamed wax blocks remained essentially the same (32%) after 8 years of exposure. The foamed rubber cover which has been exposed for over 5 years also maintained the same efficiency (86%). The two continuous wax covers which appeared to be failing at the end of 1977 continued to decrease in efficiency during 1978. The average efficiency for the year was only 47% and 68% compared to about 85% for the first 4 to 5 years of exposure. Even with the reduced efficiency, both were more efficient than the foamed wax blocks and required less material and labor to install. They would therefore be much more economical over a 6- to 8-year period than the foamed wax blocks, where they can be used.

The wax cover on the lined pond still appears to be in good condition, but is expected to gradually deteriorate as its exposure time reaches 4 to 5 years.

The five experimental foamed rubber covers being evaluated generally continue to operate satisfactorily. Thirty covers have

been constructed by the Bureau of Land Management--15 on the Arizona Strip and 15 at Safford, Arizona. Some shrinkage of the covers has been reported but they remain functional. One cover was destroyed by what appeared to be pecking--likely crows. More covers are planned by both BLM Districts during 1979.

PERSONNEL: Keith R. Cooley, Allen R. Dedrick

TITLE: CHEMICAL MODIFICATION OF SOILS FOR HARVESTING PRECIPITATION

NRP: 20810 CRIS WORK UNIT: 5510-20810-002

CODE NO.: USWCL 74-1

INTRODUCTION:

Research to develop and evaluate more effective, less costly, easily applied water harvesting treatments continued both in the laboratory and the field. Laboratory work during 1978 was concentrated on use of stabilizers, applied in conjunction with the repellents, to reduce erosion with resultant loss of runoff efficiency. Field studies were expanded (1) to include installation of several promising new treatments, (2) to use water harvesting technology for runoff farming purposes on several promising drought-tolerant new crops, and (3) to incorporate the operation of the laboratory's Granite Reef water harvesting test site.

Part I. Laboratory Studies

A number of repellents, including paraffins, residual waxes, and silicone were applied to soils which had been stabilized with cellulose xanthate; the treated soils were then subjected to accelerated weathering in either a freeze-thaw or a high-humidity chamber; and were periodically checked for resistance to water erosion and for water repellency (see previous Annual Reports for testing procedures).

Results showed that the cellulose xanthate stabilizer markedly improved the weatherability of wax- and silicone-treated soils. It also was found that antistripping agents markedly improved the weatherability of wax-treated soils. These additives also permitted lower application rates of the repellents, thus reducing both cost and use of petrochemicals.

An emulsified wax was used successfully for the first time. Emulsified waxes are appealing for runoff enhancement purposes because they are easy to apply with relatively unsophisticated equipment. Previous failure with such emulsions resulted mainly from a loss of soil structural stability. Use of a separate stabilizer eliminates this problem.

The six most promising repellent-plus-additive treatments are listed in Table 1. Material costs are listed and compared to those of three standard water-harvesting treatments (butyl, asphalt-fiberglass, and paraffin wax). For the extreme comparison, it is noted that the butyl is 74 times as costly as the slack wax + xanthate treatment. Field testing of the paraffin plus antistrip was initiated in 1978; others from Table 1 will be installed in 1979.

Part II. Field Studies

The results of water-harvesting treatment evaluations at the Granite Reef test site now appear under this reporting unit because of changes in personnel and programs at the laboratory. Rainfall-runoff efficiencies for all plots appear in Table 2. Treatment changes, which are indicated in Table 2, are elaborated on in Table 3. Treatment descriptions of the other plots under test may be found in the 1977 Annual Report.

A summary of the rainfall-runoff data for all wax plots at Granite Reef appears in Table 4. The two initial paraffin-treated plots (R-2 and T-13) and the slack wax plot (T-6) had higher efficiencies than in 1977. Several other wax (plus various additives) plots installed in 1976 were removed in 1978 due to loss of runoff efficiency or excessive erosion.

PERSONNEL: Dwayne H. Fink

Table 1. Most promising repellent water-harvesting treatments based on 1978 laboratory evaluations with material costs compared to those of three standard treatments.

TREATMENT	RATE kg/m^2	MATERIAL COST $\$/m^2$
BUTYL RUBBER		5.90
ASPHALT-FIBERGLASS		1.00
PARAFFIN	1.0	0.33
PARAFFIN + XANTHATE	0.5	0.17
PARAFFIN + ANTISTRIP	0.5	0.21
MICROCRYSTALLINE + XANTHATE	0.5	0.45
SLACK WAX + XANTHATE	0.5	0.08
SLACK WAX + ANTISTRIP	0.5	0.12
SILICONE + XANTHATE	0.018	0.21

Table 2. Rainfall-runoff from water harvesting plots at Granite Reef in 1978.

Date	Precip.	L-1	L-2	L-3	L-4	L-5	L-6	L-7	R-1	R-2	R-3	R-4	A-1	A-2	A-3	A-4	A-5
	mm	%															
9 Jan	2.8	113.7	0	0	91.1	UN	0	66.1	0	80.9	0	43.8	100.0	32.7	0	0	53.8
10	17.0	95.9	34.4	81.6	97.6	"	75.9	87.0	40.2	89.7	37.0	77.6	92.1	83.4	43.7	73.7	81.4
14-15	27.7	98.1	11.0	66.8	96.4	"	59.8	85.6	20.8	86.3	8.8	75.7	99.4	71.8	21.9	64.7	85.7
16-17	9.4	97.7	14.6	57.2	98.1	"	43.9	78.4	17.8	85.7	14.2	61.9	90.4	66.8	23.8	52.9	83.9
17	4.2	105.3	40.7	82.9	109.3	"	68.4	97.6	58.6	94.7	42.2	85.3	97.2	85.3	50.9	74.1	90.7
19-20	5.6	96.8	0	22.6	95.1	"	17.4	54.9	0	74.2	0	47.6	83.8	38.2	0	27.1	63.2
30-31	15.0	102.0	2.2	44.7	103.5	"	32.3	77.5	9.9	82.1	6.2	60.6	93.7	61.1	11.1	44.2	81.5
31-1 Feb	9.4	95.1	7.4	48.9	97.3	"	41.7	74.5	26.5	80.8	19.1	67.7	99.1	52.9	23.0	49.9	82.9
5 Feb	2.0	93.0	0	0	85.0	"	0	43.7	0	51.9	0	20.4	115.3	11.1	0	5.1	38.1
8	3.8	97.4	0	32.2	98.0	"	26.9	69.7	10.3	77.3	8.1	58.8	89.9	39.5	16.8	50.4	67.2
10-11	21.2	97.7	24.6	71.4	98.7	"	50.9	86.1	14.2	86.8	20.0	73.5	91.3	72.6	38.2	66.8	81.9
14-15	40.6	F	44.9	77.6	89.7	"	73.1	87.7	27.5	83.5	35.0	76.1	91.7	87.6	36.2	70.2	88.8
27-28	8.3	100.0	0	31.6	100.0	"	18.7	70.6	0	78.4	0	50.4	91.4	52.3	0	28.1	73.9
28-1 Mar	21.0	100.4	37.1	73.9	102.7	"	61.3	87.0	45.1	91.7	39.8	75.4	95.5	+	48.4	70.8	90.7
1-2	13.4	100.0	8.0	59.5	100.4	"	36.7	79.8	15.8	84.3	9.0	67.9	91.8	79.3	16.2	47.7	87.9
2	1.8	104.2	0	0	93.0	"	15.3	38.9	0	50.6	0	38.7	89.5	26.2	0	35.5	64.7
5	7.6	103.6	18.7	61.5	98.7	"	38.8	80.6	19.6	81.9	11.2	64.5	96.1	69.8	33.3	59.3	81.3
10-12	22.6	96.2	35.9	62.7	97.4	"	50.9	84.2	32.2	84.5	34.6	71.6	91.6	70.6	45.1	64.5	77.9
22	10.1	99.6	40.6	66.3	100.7	"	52.1	82.4	52.9	92.5	49.3	78.8	95.4	78.9	55.3	72.1	74.5
1-2 Apr	2.0	102.5	0	0	16.2	"	0	33.0	0	41.8	0	0	77.8	0	0	0	0
8	18.8	94.3	48.3	71.9	97.1	"	66.3	83.2	48.8	85.5	48.5	69.9	89.7	76.9	55.5	68.2	78.2
28 Jun	7.4	90.5	0	3.7	101.6	"	84.7*	67.2	0	66.6	0	51.8	65.3	36.0	13.5	31.1	57.1
9 Jul	2.0	98.2	0	0	95.0	"	87.5	45.0	0	37.1	0	0	87.5	0	0	0	20.2
22	50.7	F	F	F	F	"	F	F	F	F	F	F	F	F	F	F	F
24	5.3	112.9	0	30.9	M	"	M	70.5	M	53.5	0	34.5	105.8	63.9	0	31.1	64.2
2 Aug	18.5	101.0	61.7	+	102.2	"	M	101.5	57.8	89.2	59.3	76.6	101.6	89.3	66.8	75.2	78.9
3	6.6	97.7	32.9	41.6	100.7	"	M	88.0	40.8	82.5	35.6	106.1	105.6	71.5	38.3	67.3	70.6
16 Sep	6.0	104.0	0	4.3	145.4	"	M	97.5	0	95.5	0	+	137.0	55.8	+	45.8	76.2
23	4.0	89.0	0	3.5	98.7	"	M	87.7	28.1	66.5	24.4	45.6	77.5	69.4	38.3	37.5	50.4
21-22 Oct	10.7	89.2	0	1.0	75.2	"	81.2	54.7	9.5	53.8	7.7	26.1	88.0	50.2	7.5	17.8	59.4
24	5.1	94.3	0	1.9	85.6	"	89.9	62.4	0	68.1	0	29.7	90.9	45.9	0	29.6	60.6
11-13 Nov	43.0	F	10.8	+	F	"	F	F	8.0	F	14.8	53.3	F	F	18.6	44.6	F
14	1.8	95.8	0	34.1	88.9		95.8	65.3	0	87.2	0	52.6	101.8	19.4	0	50.9	73.7
15	1.8	84.2	0	17.8	72.2	"	70.8	25.8	0	47.8	0	16.5	72.5	30.8	0	11.4	46.3
23-24	17.8	96.7	0	40.7	81.2	"	93.0	66.2	3.5	74.7	0	39.0	94.4	68.0	3.7	31.6	75.2
5 Dec	4.1	92.7	0	31.3	83.5	"	87.4	60.7	0	67.3	0	31.1	87.0	47.7	0	31.8	61.6
17-19	79.8	F	11.1	13.1	F	"	F	F	15.2	F	14.9	F	F	F	21.5	F	F
29-30	11.2	95.4	0	18.3	78.0	"	88.4	46.8	0	63.2	0	16.0	93.7	56.8	0	10.4	73.6
							52.8										
TOTALS **	540.1	98.1	19.5	42.6	95.8	UN	87.9	78.8	21.1	81.0	20.2	61.9	93.3	68.7	27.2	53.2	77.2

Notation: F = overflowed storage; M = mechanical malfunction; UN = untreated; + = accumulated rainfall events;
* = initiation of new treatments, or maintenance of catchment.
** Percentage totals are based on measured data only, i.e., no estimates.

Table 2. Rainfall-runoff from water harvesting plots at Granite Reef in 1978. (Continued)

Date	Precip.	W-1	W-2	W-3	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10	T-11	T-12	T-13	T-14	T-15
	mm	%																	
9 Jan	2.8	0	0	0	+	+	+	+	+	+	+	+	+	+	+	UN	+	+	+
10 Jan	17.0	33.8	36.6	44.5	102.0	83.3	59.6	80.3	102.5	73.2	53.5	64.6	101.0	88.9	103.0	"	90.9	33.8	44.4
14-15 Jan	27.7	10.5	17.0	17.9	105.0	98.0	61.8	79.4	103.2	72.6	32.5	48.7	97.8	97.5	104.3	"	94.9	10.8	48.4
16-17 Jan	9.4	17.4	20.3	17.6	+	+	+	+	+	+	+	+	+	+	+	"	+	+	+
17	4.2	21.1	25.3	53.1	104.4	99.3	64.0	80.9	101.5	78.7	49.3	82.4	106.6	94.8	110.3	"	101.5	30.9	48.5
19-20	5.6	0	0	1.4	87.5	73.2	21.4	37.5	89.3	30.4	12.5	69.6	89.3	94.6	100.0	"	75.0	10.7	28.6
30-31	15.0	5.9	6.3	8.9	117.3	105.3	54.7	73.3	114.7	60.0	23.3	110.0	113.3	111.3	118.0	"	97.3	12.0	36.0
31-1 Feb	9.4	14.4	17.7	24.2	85.1	77.6	55.3	63.8	83.0	59.6	18.1	55.3	88.3	69.1	87.2	"	76.6	23.4	34.0
5 Feb	2.0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	"	+	+	+
8	3.8	3.9	6.4	6.8	87.9	74.1	43.1	44.8	91.4	12.1	19.0	103.4	98.3	79.3	100.0	"	72.4	8.6	27.6
10-11	21.2	19.4	26.2	29.9	103.8	100.9	81.6	82.1	103.3	75.0	36.8	61.3	105.7	88.2	105.2	"	96.7	25.5	34.9
14-15	40.6	27.4	35.4	42.8	F	F	63.3	85.2	F	80.3	39.6	41.4	F	79.3	F	"	F	33.7	38.7
27-28	8.3	3.7	5.3	7.1	101.2	92.9	40.0	52.9	100.0	36.5	18.8	81.2	104.7	70.6	107.0	"	89.4	7.0	32.9
28-1 Mar	21.0	30.2	32.4	41.6	108.6	102.4	80.9	85.2	107.1	101.9	53.3	79.5	108.1	80.0	110.5	"	100.5	44.7	47.1
1-2	13.4	7.6	10.6	12.8	104.5	97.0	52.2	66.4	100.7	62.7	20.9	79.1	105.9	83.6	108.9	"	89.5	13.4	26.8
2	1.8	0	0	0	100.0	66.7	44.4	50.0	94.4	44.4	0	100.0	116.7	55.6	111.1	"	61.1	27.8	38.9
5	7.6	14.0	20.9	24.2	105.3	97.4	64.5	68.4	103.9	48.7	34.2	86.8	110.5	89.5	107.9	"	94.7	19.7	42.1
10-12	22.6	29.2	31.6	40.7	102.2	89.8	63.7	76.1	97.3	65.9	45.1	63.7	102.2	84.9	102.6	"	87.2	5.3	35.8
22	10.1	29.5	30.4	39.3	99.0	96.0	78.2	81.2	99.0	69.3	56.4	68.3	104.9	89.1	103.9	"	113.8	39.6	52.5
1-2 Apr	2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	"	0	0	0
8	18.8	42.9	38.4	50.2	98.9	85.1	76.1	84.0	94.1	75.0	59.6	71.8	77.1	82.9	98.9		95.2	44.1	47.8
28 Jun	7.4	1.7	4.3	71.0	83.8	56.8	37.8	29.7	68.9	32.4	23.0	48.6	86.5	UN	86.5	36.5*	63.5	10.8	39.2
9 Jul	2.0	0	0	0	0	0	0	0	0	0	0	0	0	0*	0	0	0	0	0
22	50.7	F	F	F	F	F	UN	UN	F	F	UN	F	F	F	F	F	F	F	UN
24	5.3	0	0	3.3	M	M	"	"	M	M	"	M	M	M	M	M	M	M	"
2 Aug	18.5	24.2	49.7	63.6	102.7	103.8	"	"	108.6	74.0	"	84.3	97.3	47.0	99.4	37.8	F	56.8	"
3	6.6	5.7	18.7	23.8	92.4	90.9	"	"	90.9	66.7	"	68.2	98.5	39.4	100.0	28.8	84.8	48.5	"
16 Sep	6.0	9.9	11.4	12.5	83.3	66.7	"	"	75.0	46.7	"	56.7	86.7	30.0	88.3	0	80.0	16.7	"
23	4.0	0	0	0	0	0	"	"	0	0	0*	0	0	0	0	0	0	0	"
21-22 Oct	10.7	0.2	4.7	0.5	93.4	75.7	"	"	85.0	4.7	91.6	62.6	82.2	18.7	98.1	10.3	83.2	13.1	"
24	5.1	0.3	2.9	0.8	86.3	76.5	"	"	76.5	M	88.2	68.6	98.0	11.8	96.1	5.9	74.5	3.9	"
11-13 Nov	43.0	M	9.4	16.1	F	F	"	"	F	62.8	F	55.6	F	48.1	F	17.7	F	20.5	"
14	1.8	0	0	0	+	+	"	"	+	+	+	+	+	+	+	0	+	+	"
15	1.8	0	0	0	88.9	61.1	"	"	80.6	33.3	77.8	72.2	97.2	19.4	100.0	0	61.1	30.6	"
23-24	17.8	2.6	4.2	8.5	98.3	91.6	"	"	98.3	50.6	77.5	68.5	96.6	24.7	101.1	5.6	92.7	9.0	"
5 Dec	4.1	0	0	0	82.9	75.6	"	"	90.2	22.0	85.4	53.6	95.1	0	97.6	0	68.3	0	"
17-19	79.8	7.2	5.6	16.2	F	F	"	"	F	F	F	F	F	F	F	F	F	F	"
29-30	11.2	3.2	9.1	3.7	96.4	83.9	"	"	91.1	14.3	M	50.0	105.3	0	98.2	0	75.9	0	"
											38.1			86.0					
TOTALS**	540.1	15.1	20.4	24.7	97.8	88.2	60.9	74.3	95.6	62.0	83.3	64.3	96.9	31.3	100.4	15.4	87.5	23.2	40.2

Table 3. Treatment changes at Granite Reef during 1978.

I. Removed:

L-6	Installed 19 Apr 1963	Basecoat, RC-special at 1.5 kg asphalt/m^2
	Maintenance 13 Nov 1975	Sealcoat, SS2L asphalt at 2.0 kg asphalt/m^2 modified with A-1 fibers.
	Removed May 1978 Reason for removal:	Low efficiency
T-3	Installed 14 Sep 1976	Dust suppressant oil (Chevron) plus paraffin (128-131 AMP) applied as a hot melt mix in 95/5% ratio at 1ℓ/m^2.
	Removed 12 Jul 1978 Reason for removal:	Low efficiency for a wax plot.
T-4	Installed 25 Aug 1976	Blend of paraffin and ethylene vinyl acetate copolymer (Suntech, Inc.) applied as a hot melt at 0.8 kg/m^2.
	Removed 12 Jul 1978 Reason for removal:	Low efficiency for a wax plot
T-7	Installed 12 Sep 1968 Removed 12 Jul 1978 Reason for removal:	Clay asphalt Low efficiency
T-10	Installed 9 Sep 1976	Paraffin (128-131 AMP), antistrip (Dow Z-6076), tackifyer (Hercules L-60) applied as a hot melt mix in ratio of 89:1:10 at 0.75 kg/m^2 on a 2.5-cm-thick bed of medium-textured sand laid over the Granite Reef soil.
	Removed 12 Jul 1978 Reason for removal:	Excessive erosion of the unstabilized sand
T-15	Installed 16 Sep 1976	Hawaiian crude residual wax applied as hot melt at 1.0 kg/m^2.
	Removed 12 Jul 1978 Reason for removal:	Low efficiency

II. New Installations:

L-6	Installed 15 Jun 1978	Conventional asphalt-fiberglass treatment to 1/2 area, Monsanto unwoven polyester fabric - asphalt treatment to other 1/2.

Table 3. Treatment changes at Granite Reef during 1978. (Continued)

T-7	Installed 19 Sep 1978	Paraffin (128-131 scale) plus 5% by weight. Trymeen 6639 antistrip (Emery Co.) applied as hot melt at 0.5 kg/m^2 to compacted plot.
T-10	Installed 29 Jun 1978	NaCl salt plus Arizona clay (Superior Co.) applied at 25 and 140 lb, resp., were rototilled into top 2" soil and packed on 26 Jul.
T-12	Installed 27 June 1978	Subind (Chevron)

Table 4. Summary of runoff efficiencies from wax-treated plots at Granite Reef.

		Wax Treated Plots 1/							
Year	Precip.	R-2	T-13	T-6	T-3	T-4	T-10	T-15	T-7
	mm	% runoff							
1972	244	90	92						
1973	208	87	88						
1974	251	85	2/	75					
1975	183	88	96	76					
1976	193	86	91	73	90	87	85	54	
1977	116	70	77	53	61	64	53	49	
1978	540	81	88	62	61 3/	74 3/	86 3/	40 3/	83

1/ First year's data represents partial year.

2/ Missing data.

3/ Terminated during the year.

TITLE: RAINFALL, RUNOFF, AND EROSION RELATIONSHIPS FROM AGRICULTURAL WATERSHEDS IN HAWAII

NRP: 20810 CRIS WORK UNIT: 5510-20810-003A

CODE NO.: USWCL 78-5

INTRODUCTION:

The Hawaiian rainfall-runoff-erosion project conducted on six small agricultural watersheds in cooperation with the University of Hawaii, was continued through 1978. Seven years of data have now been collected, processed into engineering units, and stored on disk cartridges, ready for analysis. A SEA-WR publication that will summarize results and present the data collected through 1977 is in rough draft form. Two other publications concerned with the erosive power of Hawaiian rainfall, and the SCS runoff curve number method for estimating runoff from sugarcane and pineapple lands, are in the review process.

PROCEDURE:

Rainfall and runoff data from the six small agricultural watersheds was collected on strip charts and processed into engineering units on digitizers and computer facilities at the U. S. Water Conservation Laboratory. All rainfall and runoff data are then stored on disk cartridges for computer analysis. Sediment and erosion data are collected and processed by soil technicians from the University of Hawaii.

RESULTS AND DISCUSSION:

A brief summary of events occurring and conditions observed during the year are noted below for each site:

1. Laupahoehoe - A complete cover of sugarcane over 10 ft high covered this watershed throughout 1978. An early 1979 harvest is expected at the site.
2. Honokaa - This site also had a complete cover of over 10 ft high sugarcane during 1978, and is scheduled for an early 1979 harvest.
3. Waialua Sugar - This watershed, which was bare the last half of 1977, was planted to sugarcane about March 12, 1978. By

June 5, 1978, the cane was over 3 ft high and provided a limited ground cover, which continued until September 9, 1978, when the cane had grown to over 6 ft high, and provided a partial cover. The cane continued to provide a partial cover the remainder of 1978.

4. Waialua Pineapple - This site was abandoned in late 1977, and the equipment moved to the Helemano site.
5. Mililani - A mature pineapple crop over 3 ft high provided a complete cover on this watershed throughout 1978.
6. Kunia - A young pineapple crop provided a partial ground cover on this watershed until April 1978. By April, the crop had grown enough to provide complete cover, which existed the remainder of the year.
7. Helemano - This is a new site which was instrumented in January 1978 on a trickle irrigated sugarcane field. The cane was planted in January, and had reached a limited cover stage by mid-March. By the first of June the irrigated cane had grown enough to provide a partial cover, and a complete cover stage was reached by the first of September, and existed the rest of 1978. This irrigated site reached a complete cover stage over 2 months earlier than the non-irrigated Waialua sugar site which was planted about the same time in the same general area. It will be interesting to see if harvest is also advanced proportionately.

A SEA-WR publication intended as a means to present the data and summary of results from this project for possible use by other researchers was not completed during 1978. The 1977 data was processed and added to the 1972-1976 data for inclusion in the publication. Since several of the watersheds were harvested during 1977, adding this data increased the range of conditions which could be covered in the summary. This is especially important when studying sugarcane and pineapple culturals, because these crops cover the field such a high percent of the time, and bare soil or other non-complete covers are observed for only very short periods. Examples

of some of the tables and figures to be used in the publication were presented in last year's annual report under the title "Materials and Methods for Water Harvesting and Water Storage in the State of Hawaii."

Part of the rainfall data from this study was used to investigate the erosive characteristics of Hawaiian storms, and to determine which category of standard SCS-type storms most nearly describe Hawaiian rainfall. It was found that most of even the larger storms were of the less erosive type I and type IA category, although type II and IIA did occasionally occur. A knowledge of the distribution of erosive type storms within the year could be important to plantation managers trying to reduce erosion, which is most critical immediately following harvests. They could use the distribution information to schedule harvest periods on the most erosive potential fields for the portion of the year when erosive storms are less likely to occur.

The rainfall and runoff data was used to compute actual optimized runoff curve numbers for each site. The optimized values were then compared to handbook values established from experience on the mainland. It was found that optimized values were slightly lower than handbook values for sugarcane, and considerably lower for pineapple. The larger difference observed for pineapple may have been partially due to the effect of field roads. In the optimize procedure the percent of field roads was determined, and the curve number for the roads was established from handbook and rainulator studies. The curve numbers for the pineapple were then determined, and found to be much lower than handbook values, indicating that the pineapple offers more protection than anticipated. These results also suggest that a large portion of the runoff, and hence erosion, comes from the 10 to 20 percent of the watershed in roads. It may therefore be best to concentrate conservation measures on the roads and let contour planting take care of the cropped portion.

SUMMARY AND CONCLUSIONS:

A brief summary of cover conditions on the six watersheds for the year follows:

Two of the sugarcane watersheds had a complete cover all of 1978 and are expected to be harvested in early 1979. The other two were planted in early 1978 and both had reached the complete cover stage by the end of the year. Both pineapple watersheds had a complete cover of pineapple most of the year, one being a mature crop and the other reaching the full cover stage by April. The trickle-irrigated sugarcane site appeared to grow considerably faster than a nearby non-irrigated site, and this tendency will be observed to see if harvest time is also advanced.

A report intended to present rainfall-runoff and erosion data and analysis for these watersheds that was in rough draft form last year is being re-done to include 1977 data. Inclusion of the 1977 data was necessary to increase the range of conditions involved since four of the six watersheds were harvested and replanted during or at one end of 1977.

Generally, Hawaiian storms were found to be of the less intense type I or IA, although type II and IIA storms do occasionally occur. Runoff curve numbers obtained from rainfall-runoff data were lower than SCS handbook values, especially on the pineapple watersheds. Indications are that the 10 to 20 percent of these watersheds occupied by field roads play a significant role in the runoff and erosion processes.

PERSONNEL: K. R. Cooley

APPENDIX

LIST OF PUBLICATIONS PUBLISHED

AND MANUSCRIPTS PREPARED IN 1978

		MS No.
NRP 20740	Improve Irrigation and Drainage of Aggricultural Land	
Published:	Clemmens, A. J., and Fangmeier, D. D. Discussion of: "Border-irrigation hydraulics with zero inertia," by T. Strelkoff and N. D. Katopodes, [Jour. Irrig. and Drain. Div., Proc., Amer. Soc. Civil Engin. 103(IR3):325-342, 1977]. Jour. Irrig. and Drain. Div. 104(IR3):337-339. Sept. 1978.	652
	Clemmens, A. J. Discussion of: "Dimensionless solutions of border-irrigation advance," by N. D. Katopodes and T. Strelkoff, [Jour. Irrig. and Drain. Div., Proc., Amer. Soc. Civil Engin. 103(IR4):401-418. 1977]. Jour. Irrig. and Drain. Div. 104(IR3):339-341. Sept. 1978	644
	Clemmens, A. J., and Replogle, J. A. New flume breakthough for ditch irrigators. Irrig. Age 12(7):82-88. April 1978.	647
	Dedrick, A. R., and Erie, L. J. Automation of on-farm irrigation turnouts utilizing jack-gates. Trans., Amer. Soc. Agric. Engin. 21(1):92-96. Jan. 1978.	569
	Dedrick, A. R. and Erie, L. J. Irrigation and automation of level basins. Proc., Western Cottom Prod. Conf., Phoenix, Az., Feb. 21-23, 1978. pp. 44-46.	649
	Dedrick. A. R., Replogle, J. A., and Erie, L. J. On-farm level-basin irrigation -- save water and energy. Civil Engin. 48(1):60-65. January 1978.	618
	Erie, L. J. and Dedrick, A. R. Automation of an open-ditch irrigation conveyance system utilizing tile outlets. Trans., Amer. Soc. Agric. Engin. 21(1):119-123. Jan. 1978.	576

MS No.

Erie, L. J., Bucks, D. A., and French, O. F. Effect of water application on growing cotton. Proc., Western Cotton Prod. Conf., Phoenix, Az., Feb. 21-23, 1978. pp. 14-19. 648

Nakayama, F. S., Gilbert, R. G., and Bucks, D. A. Water treatments in trickle irrigation systems. Jour. Irrig. and Drain. Div., Amer. Soc. Civil Engin. Proc. 104(IR1):23-24. March, 1978. 605

Replogle, J. A. Discussion of: "Bibliography on discharge measurement techniques." Amer. Soc. Civil Engin. Task Comm. on Flow Measurement of the Comm. on Hydraulic Structures of the Hydraulics Div. [Jour. Hydraul. Div., Amer. Soc. Civil Engin. 103(HY8):889-904, 1977]. Jour. Hydraul. Div., Amer. Soc. Civil Engin. 114(HY4):577. April 1978. 638

Replogle, J. A., Riekerk, Hans, and Swindel, B. F. Flow metering flumes monitor water in coastal forest watershed. Water and Sewage Works Jour. 125(7):64-67. July 1978. 668

Replogle, J. A. Flumes and broad-crested weirs -- mathematical modeling and laboratory ratings. In: "Flow Measurement of Fluids." Proc. FLOMECO, 1978. The Netherlands. H. H. Dijstelbergen, E. A. Spencer (Eds.). North-Holland Publishing Co. pp. 321-328. 1978. 653

Replogle, J. A., Dedrick, A. R., and Erie, L. J. Irrigating with level basins. Ariz. Prof. Engin. 30(10):4-5. October 1978 678

Prepared:

Bucks, D. A., Nakayama, F. A., and Gilbert, R. G. Trickle irrigation water quality and preventive maintenance. Agric. Water Management. (Submitted for publication) 669

Clemmens, Albert J., and Replogle, J. A. Constructing simple measuring flumes for irrigation canals. USDA Farmers Bulletin. 1979. (In press) 695

	MS No.
Clemmens, A. J., and Strelkiff, Theodor. Dimensionless advance for level-basin irrigation. Jour. Irrig. and Drain. Div., Amer. Soc. of Civil Engin. (Approved for publication)	674
Clemmens, Albert J. Verification of the zero-inertia model for border irrigation. Trans., Amer. Soc. of Agric. Engin. (In press)	670
Erie, L. J., and Dedrick, A. R. Level basin irrigation: A method for conserving water and labor. USDA Farmers Bulletin No. 2261. (In press)	646
Gilbert, R. G., Nakayama, F. S., and Bucks, D. A. Trickle irrigation: Prevention of clogging. Trans., Amer. Soc. Agric. Engin. (In press)	645
Nakayama, F. S., Bucks, D. A., and Clemmens, A. J. Assessing trickle emmiter application uniformity. Trans., Amer. Soc. Agric. Engin. (In press)	659
Replogle, J. A., and Clemmens, A. J. Broad-crested weirs for portable flow metering. Trans. Amer. Soc. Agric. Engin. (Submitted for publication)	681

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Published:

Aase, J. K., and Idso, S. B. A comparison of two formula types for claculation longwave radiation from the atmosphere. Water Resources Res. 14(4):623-625. Aug. 1978 686

Brazel, A. J., Fritts, H. C., and Idso, S. B. The climate of Arizona: Prospects for the future. Ariz. State Univ., Lab. of Climatology Publication. 1978. 661

Ehrler, W. L., Idso, S. B., Jackson, R. D., and Reginato, R. J. Diurnal changes in plant water potential and canopy temperature of wheat as affected by drought. Agron. Jour. 70(6):999-1004. Nov-Dec 1978. 628

Ehrler, W. L., Fink, D. H., and Mitchell, S. T. Growth and yield of Jojoba plants in native stands using runoff-collecting microcatchments. Agronomy Jour. 70(6):1005-1009. 640

Ehrler, W. L, Idso, S. B., Jackson, R. D., and Reginato, R. J. Wheat canopy temperature: Relation to plant water potential. Agronomy Journal 70(2):251-256. Mar-Apr 1978. 595

Hatfield, J. L., Reginato, R. J., Idso, S. B., and Jackson, R. D.. Surface temperature and albedo observations as tools for evapotranspiration and crop-yield estimation. In COSPAR: "The Contribution of Space Observations to Global Food Information Systems." E. A. Godby and J. Otterman, (Eds.) Pergamon Press, Oxford and New York. pp. 101-104. 1978. 632

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Idso, S. B., and Brazel, A. J. Climatological effects of atmospheric particulate pollution. Nature 274(5673):781-782. August 1978. 657

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