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

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U. S. WATER CONSERVATION LABORATORY
Agricultural Research Service
U. S. Department of Agriculture
Western Region
4331 East Broadway
Phoenix, Arizona 85040

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PERSONNEL

The laboratory staff is as follows:

Permanent Employees:

Allen, Robert F.	Electronic Engineer (resigned 6/82)
Auer, Gladys C.	Physical Science Technician
Bell, Frieda L.	Clerk-Typist
Bishop, Mary H.	Clerk-Typist (transferred 8/82)
Bouwer, Herman	Research Hydraulic Engineer, Research Leader, and Laboratory Director
Bowman, Robert S.	Soil Scientist
Bucks, Dale A.	Agricultural Engineer
Clemmens, Albert J.	Research Hydraulic Engineer
Davis, Sonya G.	Engineering Draftsman
Dedrick, Allen R.	Agricultural Engineer
Ehrler, William L.	Plant Physiologist
Ezra, C. Elaine	Physical Scientist
Fink, Dwayne H.	Soil Scientist
French, O. Fred	Agricultural Research Technician
Gerard, Robert J.	Laboratory Support Worker
Gilbert, R. Gene	Soil Scientist (transferred 6/82)
Hohman, Judy P.	Biological Technician
Idso, Sherwood B.	Research Physicist
Jackson, Ray D.	Research Physicist
Kimball, Bruce A.	Soil Scientist
Legard, Wilde W.	Agricultural Research Technician
Lewis, Clarence	Machinist
Martinez, Juan M. R.	Hydrological Technician
Mastin, Harold L.	Computer Assistant
Miller, J. Bennett	Biological Laboratory Technician
Mills, Terry A.	Computer Specialist
Mitchell, Stanley T.	Physical Science Technician
Moore, Linda	Biological Technician (resigned 2/82)
Murphy, B. Lenore	Clerk-Typist
Nakayama, Francis S.	Research Chemist and Research Leader
Pettit, Dean	Electronic Engineer
Pinter, Paul J.	Research Entomologist
Rasnick, Barbara A.	Physical Science Technician
Reega, Marilyn T.	Secretary
Reginato, Robert J.	Soil Scientist and Research Leader
Replogle, John A.	Research Hydraulic Engineer & Research Leader
Rice, Robert C.	Agricultural Engineer
Rish, Shirley	Clerk-Typist
Schnell, Stephanie	Biological Aide
Seay, L. Susan	Clerk-Typist
Seay, Ronald S.	Agricultural Research Technician
Tyrrel, Jerry	Physical Science Technician

Personnel (continued)

Temporary Employees:

Anderson, Mike	Co-Op Agreement (Biological Technician)
Benjamin, Mike	Work Study (Maintenance Helper)
Bordynoski, Joe	Work Study (Maintenance Helper)
Carney, Brian	Computer Clerk
DeJuan, Jacinto	Engineering Technician
Dierig, David A.	Agricultural Research Technician
Dust, Jonathan	Electronic Technician
Hoque, Enamul	Research Assistant (ASU)
Jacobs, John S.	Electronic Technician
Jimenez, Leonardo	Engineering Draftsman (resigned 7/82)
Koenig, Chris	Work Study (Maintenance Helper)
Nieto, Santos	Co-Op Agreement (Electronic Technician)
Ottersen, Scott	Biological Aide
Pendrick, Annette M.	Biological Aide
Reeves, Kathy	Biological Aide
Reynolds, Cauleen	Work Study (Clerical)

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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

INTRODUCTION:

The long-throated flumes, particularly the broad-crested weirs, are being widely accepted by the irrigation community worldwide as the preferred device for open-channel flow measurement. Their flexibility in size, liberal construction tolerances, low head-loss requirements, and cross-sectional shape permit them to be retrofitted to most canals. Computer modeling techniques continue to be applied to special problem sites.

BOOK DRAFT ON FLUMES:

The review draft of the book entitled "Flow Measuring and Regulating Flumes" by Bos, Replogle and Clemmens was completed in August 1982. It was sent out for review and nearly all copies have been returned. Draft copies were sent (according to copy number):

2. Professor Kraijenhoff van deLeur - University of Agriculture, The Netherlands

3. Ir. Storsbergen - DHV Consulting Engineers

4. Ing. Boiten - Delft Hydraulics Laboratory

5. Ing. Bol - Water Management and Hydrology Department of Rijkswaterstaat

6. M. Decroix - Office of Minister of Agriculture, France
EYROLLES - publisher

7. Jose Antonio Ortiz - ICID, Spain

14. NTE

16. John Wiley and Sons - publisher

17. Thomas Trout, Jim Bondarant, Al Humphries, Chuck Brockway - Snake River Conservation Laboratory, ID

18. McGraw-Hill - publisher

19,20. Swayne Scott - Soil Conservation Service, Washington, DC

21. James E. Carlson - U. S. Department of Interior, Bureau of Reclamation, Denver, CO

22. Dr. Clyde - Utah State University, Logan, UT

23. Al Halderman - University of Arizona, Tucson, AZ

24. A. R. Robinson - retired

25. E. Gordon Kruse - ARS, Ft. Collins, CO

26. Jim McDade - Salt River Project, Phoenix, AZ

27. Steven Tannis - Salt River Project, Phoenix, AZ

Useful comments were received from many reviewers. These will be incorporated into the text as soon as possible. The book was originally designated for publication by the USDA. However, due to the content of the book we would prefer outside publication. The English version has been declined by McGraw Hill and Academic Press. Elsevier appears interested. We have contacted a French publisher that is interested in translating the book to French. A Spanish version will be published by ILRI if no other publisher can be found.

The book contains a significant amount of published work. However, a majority of the book contains new information, revised work or old work reformated for easier use. For those interested in designing these flumes for open channels, the book is somewhat all encompassing. In addition, there is a considerable amount of information on the design of canal systems and on open channel hydraulics in general.

New developments in the book include the new furrow flume designs (the old design was never published), a new portable rectangular flume, new calibrations for trapezoidal, rectangular and v-shaped control sections, a summary of head detection methods, designs for movable weirs, data sheets for collecting design information, a systematic approach to the design of energy dissipation structures, summary of flume construction techniques and a simplified, revised computer model.

Problems had developed with the v-shaped furrow flumes. The Froude numbers became large very fast because of the small approach area. The blunt (or reentrant) approach condition added to standing waves in the approach section. The basic shape of the approach was changed to a trapezoid with a bottom width $b_1 = 1/2\ b_c$ and sideslopes of 0.5:1 (horizontal/vertical). This resulted in a capacity of nearly twice the discharge at a Froude number of 0.48, the limit placed on these flumes. Wing walls were added to reduce the entrance effects. The stilling well was moved to the side of the flume, out of the way. This was possible because of the steeper sidewalls. The stilling well is now about twice as far from the survey point thus more care is needed at leveling the flume in the cross direction.

LARGE FLUMES:

The large flume constructed on the Arizona canal in November, 1981 has been operating successfully for over a year. Current meter readings were taken throughout the growing season. The weir was generally within ± [illegible]% of the current meter data. The maximum flow during the season was abo[illegible]

1600 cfs. We predicted that the modular limit would be exceeded at about 1400-1500 cfs. However, the measured tailwater level was higher than the original estimate. Thus, the new calculated submergence occurred at about 1080 cfs. This was visually verified. The flume was constructed 0.7 feet too low originally. It was raised 0.6 feet in October, 1982 by adding a cap to the flume throat. A weir was also constructed on the South Canal in November, 1982. This weir is 60 ft. wide, 5 ft. high and has a capacity of 1500 cfs. Thus, all diversions from Granite Reef dam to the Salt River Project are monitored with flumes. A large flume of 500 cfs capacity was constructed on the Lost River in Idaho. A trapezoidal approach channel section was constructed along with a wide trapezoidal throat.

LABORATORY STUDIES:

The hydraulics lab is now partially operational. The new bypass pipe between the sumps appears to have developed a serious leak. The constant head tank is functioning well, but not all valves in the piping have been extended through the floor for access. Plans have been prepared for a weighing tank system. The plans are being reviewed and will then go out for bid.

A preliminary study is underway on sediment transport in channels. The sediment movement characteristics of one type of sediment is being studied under different flow conditions, sediment loads and (rectangular) flume height in a rectangular channel. Another type of sediment is available for testing. A trapezoidal channel was built for future testing of these two sediment types. Sills with flat and v-shaped bottoms are available and will be tested.

EXPANDED COMPUTER PROGRAM:

The flume program presented in the book has been expanded to cover; both English and metric input and output units, a wide variety of flume shapes, plotting routines for wall gauges and flume calibrations, and movable or stationary weirs. This program will enhance our ability to design flumes for a wider variety of conditions. A good example is the design of bottom sills in circular channels. A manuscript has been published on these flumes that give ratings for a wide variety of sill heights and pipe diameters.

MISCELLANEOUS:

Getting the message out to irrigation projects throughout the U.S. and the world continues to be a problem. Formal channels of technology transfer are virtually nonexistent. Most people learn of these flumes by word of mouth, technical publications, or news releases. In most cases, the information obtained is incomplete thus requiring additional assistance. We continue to assist irrigation (and drainage) districts in the U.S. and throughout the world. The book should reduce this assistance load to the few cases where complex problems exist. Design assistance was provided to a number of individuals, irrigation districts, government agencies etc., located in Imperial Valley, CA, Lost River, ID, San Luis, CO, El Paso, TX, Safford, AZ, Thailand, etc.

Four workshops were held on flow metering. One for the Arizona Department of Land Management and three for the Soil Conservation Service in Colorado.

Gauges painted on canal walls in Utah are being tested as to their longevity and useability for use with these flumes.

SUMMARY AND CONCLUSIONS:

The manuscript on the book "Flow measuring and regulating flumes" has been completed and reviewed. The comments were, in general, favorable, although a number of critical reviewers provided some valuable suggestions. These will be incorporated in early 1983. Arrangements have been made to translate the book for publication in both Spanish and French. A publisher has not been found for the English version. A shorter summary of our previous work was published in a book chapter in Advances in Irrigation edited by D. I. Hillel, Academic Press.

The furrow flumes that were developed several years ago and have experienced wide usage have been redesigned. The 90-degree v-shape was changed to a trapezoidal shape with 1/2 horizontal to 1 vertical sideslopes. The new flumes have doubled the flow capacity for the same overall flume size. In addition, the steeper sidewalls allow the placement of the stilling well on the side of the flume where it does not obstruct the flow nor catch debris.

A new portable flume has been developed for use in unlined canals or lined canals (at low flow). A sill is placed in a rectangular channel constructed of plywood. For lined canals, the structure is the same width as the channel bottom and wingwalls are used to control flow past the sides of the flume. The differential water pressure holds down the flume which floats when it becomes submerged.

The Salt River Project has had continued success with the modified broad-crested weir in many applications. The large weir (54-ft wide) on the Arizona Canal has been successfully operated for a full irrigation season. The weir was checked against current meter readings during the season, with good agreement. A 60 ft wide weir was also constructed on the south canal in November 1982. Thus, all diversions for the project are now monitored with this style of flume. Widespread use of these devices in the project has lead to a 20% increase in the "apparent" water availab[illegible]. This results from accurate monitoring of water divided and diverted and the identification of unknown water losses.

Four workshops on flow metering were conducted. One for the State of Arizona Department of Land Management and three for the Soil Conservation Service in Colorado. Design assistance was extended to several other irrigation districts in the west: Imperial Valley, CA: Lost River, ID; San Luis, CO; El Paso, TX; as well as many irrigation districts within

Arizona -- Parker, Wellton, Safford, Phoenix, etc. Foreign inquiries have been extensive. A firm in Thailand is computing special shapes from our model for application there.

The number of flume shapes is continually being expanded. The computer program on flume calibrations has been expanded to handle the following cross-sectional shapes for the approach, control and tailwater sections; 1) simple trapezoid, 2) complex trapezoid, 3) circle, 4) U-shaped, 5) parabolic. Additional cross-sectional shapes for the control section include both bottom sills and trapezoidal sections in circular, U-shaped and parabolic channel. A manuscript on bottom sills in circular channels has been accepted for publication.

Preliminary studies have been undertaken to study the nature of sediment transport in channels and the effect of measuring structures on this transport. Sediment-injection equipment has been built to provide constant and adjustable rates of sediment in a flowing channel so that the sediment-clearing capabilities of several flume shapes can be tested. A primary laboratory calibration system has been designed and is being processed for construction bids.

PERSONNEL: J. A. Replogle and A. J. Clemmens

TITLE: MATHEMATICAL MODELING OF BORDER IRRIGATION HYDRAULICS

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

INTRODUCTION:

The modeling of surface irrigation systems is in considerable demand. These models are useful for a variety of purposes such as: irrigation system design, evaluation and management; evaluation of runoff and associated erosion and water quality degradation; evaluation of irrigation effects on agricultural return flows; and the evaluation of new irrigation techniques. The zero-inertia concept of irrigation flow modeling has been a significant contribution toward the above objectives. In general while significant progress has been made, these models have not been effective. Thus additional work is required at developing reliable, useful models and at developing analysis techniques which utilize the models for specific applications.

New Program for Border Flow - BRDRFLW:

The zero-inertia border-irrigation mathematical model was last documented in 1977. At that time, a locally linearized set of algebraic equations was used to approximate a mix of integrated and differential forms of the equations of continuity and motion. The present equilibrium model is based wholly on integrated forms. Statements of mass conservation and equilibrium of forces are applied to thick slices of the surface stream; the continuity equation, further, is integrated over small increments of time. Simple quadrature formulas, notably the trapezoidal rule, are used to approximate the integrals by algebraic expressions. The model documented in 1977, furthermore, was not programmed to treat irrigation streams ponded behind dikes raised at the downstream end of the field. Recession from the front of the irrigation stream, either before advance was completed or after, also could not be modeled. The present model is capable of treating both of these circumstances.

Additional bases for mathematical modeling are provided in the current model by normal-depth kinematic-wave theory. If the depth in the surface flow is sufficiently small compared to the bottom slope, the depth and discharge at every point in the stream are uniquely related through a normal-depth stage-discharge relationship. This allows simpler, quicker, more robust* computations than those provided by equilibrium (zero-inertia) theory. The range of applicability of the kinematic-wave model can be greatly extended, if application of kinematic-wave theory is deffered until water starts to recede from the upper end of the field. Such a hybrid model constitutes a subset of BRDRFLW, as does pure kinematic-wave theory. These can be called for as desired by the user.

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*Less subject to computed saw-tooth profiles and spontaneous aborts of computer runs.

The present equilibrium model differs also from its more recent, undocumented, predecessors in several substantial ways. The length δx of cells making up the surface stream has been divorced from the time step δt. For quick, rough computations the number N of cells can be set to small constant, say, N = 5. Previously, the number of cells equaled the number of time steps of advance, which results in unnecessarily large numbers of computations. The present system also allows the computational field length to be precisely equal to the given field length, rather than somewhat larger in accordance with the advance achieved in an integral number of time steps, as in the earlier models.

The surface-stream profile is found at each time step either iteratively, through the Newton-Raphson method of solving the nonlinear governing equations, or in a single set of implicit computations utilizing locally linearized forms of the equations. The latter calculation is merely the first step of the former. When used, the Newton-Raphson method typically converges in about 3 or 4 iterations.

The skeleton of BRDRFLW is built in such a way that variations in the functional form of inputted conditions are relatively easily accommodated. For example, when in the course of computation the program requires a value of inflow discharge at time t, a call is made to the function subprogram QF(t). Any desired inflow-hydrograph function can be inserted in the subprogram. Similarly, the program's need for a value of time step, say of time t, results in a call to DTF(t); any desired variation in time-step size can be specified in that one subprogram. Variable bottom slope is handled as follows: in the statement of equilibrium amongst all forces acting on water in a cell, the pertinent geometrical feature of the bottom is the difference in elevation at the upstream and downstream ends of the cell. The subprogram BF(x) provides the bottom elevation at point x. Any desired variation can be programmed into that routine.

The roughness of the bottom is characterized by the Chezy C, which in general is a function of depth y. The subprogram CHEZY C, which has amongst its arguments y, RUF, a_n, and RUFMOD, computes the CHEZY C on the basis of the computer-supplied y and the roughness parameter RUF, read in at the start of the computation. The index RUFMOD, also supplied by the user, determines the nature of the roughness formula to be used. With RUFMOD set to 1, RUF is interpreted as a constant CHEZY C value. With RUFMOD = 2, RUF represents the Manning n. Some researchers allow the Manning n to vary as a power law of depth (reflecting the fundamental unsuitability of the Manning formula for shallow flow) to allow comparison with the results of these researchers, the CHEZY C routine utilizes the following formula when RUFMD = 2: n = RUF $\cdot$ $y^{a}n$; in the usual case, a_n = 0. With RUFMOD = 3, RUF is interpreted as the Sayre-Albertson χ (chi), in their logarithmic formula, considered theoretically more sound than the Manning formula.

Cumulative infiltration z (and infiltration rate) is also relegated to a subroutine whose principal argument is τ, the infiltration time. The formula currently programmed is rather general: $z\ k\tau^{a} + b\tau + c$, with a, b and c supplied by the user. With b = 0 and c = 0, the formula is the

Kostiakov function; with b = 0, the results represent the SCS formula typifying their infiltration families; with a = 1/2, c = 0, the result is the Philip formula.

In order to save computation time in the ponded case, the computer can recognize a nearly stagnant state of the surface stream and compute recession times directly, based on a level water surface and a typical flow depth. Alternately, the program works in the usual mode, computing at successive times the positions of the essentially horizontal water surface as it slowly lowers as the result of infiltration into the soil.

Input data can be entered in either metric or English units, or in dimensionless form. Setting an index (DMLMOD) determines the system of non-dimenionalization used by the program. With data entered in dimensional form, the desired set of characteristic values is used to put them in dimensionless form. The computations, in any case, are carried out in dimensionless form, with intermediate results, say, at each time step, printed in dimensionless form. Final results — the advance and recession functions, ultimate distribution of infiltered water, runoff volumes, etc. — are presented in all sets of units.

To enhance the significance of dimensionless input, the program computes the corresponding dimensioned values for a hypothetical border. Hypothetical values of border roughness, slope, and inflow, needed to interpret physically dimensionless input are entered by the user, or default values can be supplied by the program.

In general, input data defining solution methods and parameters rather than physical-problem parameters have program-supplied default values, which are enabled by entering 0 (zero) for each such variable value called for.

The computer program is extremely flexible, both in terms of input options and in terns of changes in coding required for additional changes. The input lines for the program are given in Table 1. Lines 1 and 2 are self-explanatory. Line 3 sets up the unit's system and gives options of what data are to be entered new. Lines 4-8 give the physical data for the run (e.g., a given irrigation). Lines 9-10 determine the modeling parameters. Line 11 determines the type and amount of output and line 12 gives the parameters for plotting. The program returns to line 1 for the next set of input data. It can be run in either batch mode or interactively. It is currently programmed in Fortran IV on the MNF4 computer at BKY, the computer center of the Lawrence Berkeley Laboratory, University of California, Berkeley. Details of the variables input and their meaning will be documented in a users' manual. Future additions include; 1) infiltration as a function of distance as well as time, 2) inflow stream size as a function of time, and 3) capability of modeling surge flow.

Modeling Conference:

An informal conference on surface irrigation modeling was held on 17-18 August 1982 at the U. S. Water Conservation Laboratory. It was attended by:

Day Bassett	Washington State University, Ag. Eng. Dept.
Bert Clemmens	U. S. Water Conservation Lab., Phoenix, AZ
Guy Dickey	SCS State Irrigation Specialist, CA
Lee Hardy	SCS State Irrigation Specialist, AZ
Jobaid Kahbir	Washington State University, Ag. Eng. Dept.
Terry Podmore	Colorado State University, Ag. & Chem. Eng. Dept.
John Replogle	U. S. Water Conservation Lab., Phoenix, AZ
Fedja Strelkoff	San Francisco, CA
Wynn Walker	Utah State University, Ag. & Irrig. Eng. Dept.
Wes Wallinger	Univ. of Calif., Davis, Dept. Land, Air & Water R
Muluneh Yitayew	Univ. of Arizona, Dept. Civil Eng. & Eng. Mech

There was a short discussion on the status of border irrigation models. With the near completion of current work, the border model will be complete enough for field use. However, some additional analysis work is required to make the results of the model field useable. Guy Dickey expressed a need for making quick recommendations following an evaluation.

Furrow irrigation models are still in the development stage. Several researchers have developed furrow models for various uses. The model of furrow advance based on zero-enertia developed by Francisco DeSouza under direction of Fedja Strelkoff was never published. It was used to evaluate the different methods of assessing furrow infiltration. The methods employed were:

1) Assuming a constant wetted infiltration area based on the wetted perimeter for normal depth.

2) Assuming a constant wetted infiltration area based on the wetted perimeter for the upstream depth.

3) Assuming a wetted infiltration area based on the local calculated top width, where infiltration is assumed to start over the entire width at the same time.

4) Same as 3) based on local wetted perimeter.

5) Same as 4) except incremental infiltration start time is calculated for each increment of wetted perimeter as it is wetted.

Methods 3) and 4) appeared to give the best results.

Jobaid Kahbir, working under Day Bassett, has developed a furrow irrigation model (based on DeSouza's work) for the study of erosion and runo in furrows. Independently, Ron Elliot (formerly at Colorado State University, now at Oklahoma State University) developed at furrow model based on the original ZI border model by Katapodes and Strelkoff. Wyn Walker (and students) have modified Elliot's model to handle surge flo Walker and crew have also developed a kinematic wave model for furrows.

Walker tested the furrow models with infiltration data taken with his new "flowing" furrow infiltrometer. This infiltrometer uses water flowing in a furrow between two sumps. Water is pumped from and returned to a 50-gallon drum. A constant water level is maintained in the furrow. Thus the drop in water level in the 50-gallon drum is proportional to furrow intake. Walker reported good correlation on advance when the infiltrometer flow was one-half of the inflow to the furrow, (these tests are run separately). Additional work is required along these lines.

Still the problem of quick, easy analysis for on-site recommendations is quite a way off.

Roughness Data:

Data from the 1979 experiments at the Cotton Research Center were analyzed to determine the resistance to flow in borders planted to alfalfa. The data were not very precise and not enough data were taken. However, these general observations were made. The data is given in Table 2.

1) Manning roughness values decrease with increasing flow rate. This trend matches theoretical predictions.

2) Manning roughness values are not effected by field slope.

3) Roughness seems to decrease down the border. This in part contradicts 1) above.

Considering the variations in computed roughness, the reasonable closeness of median roughness values and the relatively small effect that roughness has on the final distribution of water, we are justified in using the computed median roughness values. Comparisons of advance and recession data further verify the minor effects of roughness (at least relative to other parameters).

SUMMARY AND CONCLUSIONS:

The emphasis over the last year has been to finalize the development of a new border irrigation computer program "BRDRFLW." This program was developed under contract. It is considerably more versatile than previous programs and has been developed for use by those not directly familiar with irrigation modeling or model details. This program contains several mathematical models of various sophistication; kinematic wave, zero-inertia (both linearized and fully nonlinear versions) and a hybrid KW-ZI model.

In addition, the program has options for variable bottom slopes and can handle a variety of infiltration functions, and roughness functions. The model can be run in English, metric or nondimensional units. Most of the solution parameters can be defaulted for simplified use. A plotting routine is available for plotting depth and elevation profiles. The output consists of advance, recession, infiltrated depths and different measures of irrigation performance. Information summaries at each time step can be obtained by specifying the appropriate diagnostic levels. Additional features can be added to the model relatively easily. These include specifying infiltration as a function of distance or location and varying the inflow stream size as a function of time. A considerable amount of programming would be necessary to handle surge flow, although it is possible. A users' manual for the program should be available soon.

A conference was held to determine the status of existing furrow modeling efforts. It was attended by the Soil Conservation Service personnel and irrigation modelers from several locations. The conclusions reached by the group were: 1) furrow irrigation models exists, 2) some data have been collected to check their validity, 3) advance and recession can be modeled reasonably accurate provided that infiltration information is available, 4) some questions still remain as to how to handle infiltration in the model and how to determine it in the field, 5) assessing roughness is of minor concern, 6) a considerable amount of effort is needed before such models can be used for either design or management recommendations and decisions in the field.

REFERENCES:

Elliott, R. L., W. R. Walker, and G.V. Skogerboe, "Zero-Inertia Modeling of Furrow Irrigation Advance," Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, Vol. 108, No. IR3, September 1982, pp. 179-195.

PERSONNEL: A. J. Clemmens

Table 1: Input Lines for Border Irrigation Program BRDRFLW, December 1982.

Parameters	Permissible Values	Function	Defaults
Line 1			
---	0,1	terminate or continue	
Line 2			
---		run identification	
Line 3			
TSTMOD	0,1,2,3,4,5	indicates data lines to be entered	
INPMOD	1,2,3	indicates input units	
DMLMOD	0,1,2	dimensionless scheme	0 → 1 or 2
Line 9			
SOLMOD	0,1,2,3,5	indicates solution technique	0 → 2
LINMOD	0,1,2	solution linearity	0 → 2
DTMOD	0,1,2	controls variation in DT	0 → 1
ZADMOD	0,1,2	controls options for stagnant ponding	0 → 2
Line 10			
N(STD)		number of stream increments	0 → 20
RDX		ratio of cell sizes	0 → 0.8
DT(STD)		standard time step	
TMAX		maximum irrigation time	0 → 800*DT(STD)
Line 11			
IDIAG	0,1,3,5,7	amount of diagnostic info.	0 → summary only
IDCH		time step of diagnostic change	0 → no change
IDIAG		new value for IDIAG	0 → no change
Line 12			
---		plotting parameters (8)	0 → no plot
Line 4			
RUFMOD	1,2,3	roughness function	
RUF,AN		roughness parameters	
INFMOD	1,2	infiltration function	
K,A,B,C		infiltration parameters	
Line 4a			
CHI*		Sayre-Albertson roughness parameter	
Line 5			
L or L*		field length	
DBC	1,2	field end conditions	
SOMOD	1,2	bottom configuration	
Line 6			
SOAVG		bottom slope (SOMOD = 1)	
or			
N20		number of distance/elevation data pairs	
XZO(1),ZO(1)...		distance and elevation values	
Line 7			
ZREQ		required depth of infiltration	
QIN		unit inflow rate	
TCO		time of cutoff	
or			
ZREQ*,TCO*		above for INPMOD = 3, DMLMOD = 1	
or			
ZREQ*		above for INPMOD = 3, DMLMOD = 2	
Line 8			
INPMDH	0,1,2	dimensional system for hypothetical example	0 → default for below
SOAVG		slope for hypothetical example DMLMOD = 1	0.001
QIN		unit flow rate for hypothetical example	6 l/sm
TCO		cut-off time for hypothetical example, DMLMOD = 2	120 min
Line 8a			
RUF		roughness parameter for hypothetical example RUFMOD = 1	
or			
RUF,AN		roughness parameters for hypothetical example RUFMOD = 2	

Table 2: Roughness Values Computed for Data From CRC, 1979 Experiments.

			Manning Roughness Values		
Border #	Slope	Unit Flow Rate (cfs/ft)	Avg. of Medians	Median of Medians	Range of Medians
1	0.000	0.0675	0.183	0.192	0.283 - 0.07
3		0.1016	0.125	0.109	0.203 - 0.07
4	0.001	0.0678	0.147	0.120	0.205 - 0.08
6		0.1016	0.133	0.124	0.161 - 0.09
7	0.0005	0.0677	0.177	0.177	0.237 - 0.13
9		0.1016	0.145	0.118	0.203 - 0.10

TITLE: IRRIGATION WATER MANAGEMENT FOR RICE PRODUCTION IN THE SOUTHWESTERN UNITED STATES

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

INTRODUCTION:

Rice research began in 1979 at El Centro, California, and Yuma, Arizona. The objectives of these experiments have been: (1) to determine rice cultivars suitable for an arid environment, and (2) to evaluate the effects of irrigation regime and planting data on non-paddy rice production, using level-basin irrigation systems. In 1982, the following two objectives were added: (1) to evaluate the effects of increased irrigation during critical plant growth stages, and (2) to determine if irrigation water of a marginal quality could be utilized for rice production in an arid environment. This annual report includes information obtained from El Centro for 1981, partial information from El Centro, and all information from Yuma for 1982.

El Centro, California

Field Procedures:

Four investigations were conducted in 1981 at the Imperial Valley Field Station, El Centro, California, with the primary purpose being to continue identifying rice cultivars suitable for desert irrigation practices. All of the first three experiments were planted under three irrigation treatments of flood (paddy), 3-day, and 6-day irrigation frequencies.

The first experiment was called 1981 intermittent irrigation experiment - advanced cultivars. Fifty entries were planted on May 1, which included 31 of the best lines from the 1980 experiment plus 19 new lines added in 1981. Each entry was planted in rows 2.4 m (8 ft) long on 30-cm (12-in.) centers and replicated four times. A seeding rate of 8 grams per row was used. Ordram (molinate, S-Ethyl hexahydro-1, H-azepine-1-carbothioate) was applied at about 34 kg/ha (30 lbs./acre) as a preplant herbicide, and Stam M4 (propanil, 3', 4'-Dichlorophenyl -propionanilide) at a rate of about 7 liters/ha (3 qts/acre) was also applied for control of grasses. Nitrogen fertilizer was applied at 68 kg/ha (60 lbs/acre) preplant, 68 kg/ha (60 lbs/acre during tillering, and 100 kg/ha (90 lbs/acre) at the boot (or early panicle initiation) stage.

Of the 50 entries that were used in the first experiment, there were 31 entries from the 1980 advanced cultivars experiment and 19 new lines that were added from other investigations. All the selected entries have been selected from introductions grown over a 12-year period at El Centro. In all cases, seeds of known origin either paddy (flood), 3-day, or 6-day irrigation treatments have always been kept separate.

In 1981, cultivars IR 22, IV 213, IV 330-1, IV 404, T1, and IR 1108-3-5-3-2 were planted using seeds from the three irrigation treatments. All the other lines were planted using seeds produced from the previous years' paddy irrigation, because this treatment usually produced the most seed. Data obtained included general appearance, heading date, plant height, panicle exsertion, grain type, percent lodging, percent sterile panicles, percent blanking, weight per 1000 seeds, stem angle, and yield. The 1000 seed weights were taken from machine counts made on air-cleaned seed, which should have resulted in more reliable information than the weight of 200 seeds used in prior years.

The second experiment was named 1981 intermittent irrigation experiment - new cultivars. This experiment included 20 superior cultivars selected from the 1980 USDA rice introduction nursery and seven check cultivars. Irrigation treatment, plot size, replication number, seeding rate, and herbicide and fertilizer procedures were the same as the first experiment. On the lines that were discarded prior to the 1981 planting date, abbreviated data included general appearance, heading data, plant height, panicle exsertion, grain type, percent lodging, percent sterile panicles, stem angle, and yield.

The third experiment was called 1981 intermittent irrigation experiment - natural selection. The purpose of this experiment was to obtain uniform seed and to determine if seed originating from either the 1979 or 1980 paddy, 3-, and 6-day irrigation treatments could be improved through natural selection. Plot size and other agronomic practices were the same as the two previously described experiments and the information obtained was identical to the abbreviated data listed for the second experiment. The fourth area of work was to select superior lines from a 1981 USDA introduction nursery of 1,119 lines from throughout the world. A paddy irrigation practice was maintained on the introduction nursery.

In the 1982 plantings which are still being analyzed, the five main components were: (1) advanced cultivars, (2) new cultivars, (3) special irrigations, (4) new upland cultivars, and (5) introduction nursery. The four experiments contained 50, 36, 2, 37, and 649 entries, respectively. For the intermittent irrigation experiment - advanced cultivars, 31 entries were again retained from the 1981 experiment; and 19 new lines were added from other 1981 experiments. For the intermittent irrigation experiment - new cultivars, 32 new lines plus 4 check cultivars were included with only a single replication under the same three irrigation treatments previously described.

The 1982 intermittent irrigation experiment - special irrigations, involved three separate parts: (1) Maintain irrigations under a continuous paddy (flood) condition. (2) Irrigate at 3-day intervals until the cultivars IR 22 and IV 404 were in early boot, followed by continuous paddy until 12 days after heading for the two cultivars; thereafter, irrigations were applied on 3-day intervals for 18 more days and then terminated. (3) Irrigate the same as the previous treatment except substitute 6-day for the 3-day frequencies. (4) Irrigate on a 6-day interval until August 1, then paddy until September 1, and followed by a 6-day frequency for 24 days (after IR 22 and IV 404 have headed) before termination.

The third experiment originated from a request to the International Rice Research Institute in the Phillippines for a sampling of upland rice cultivars from 10 different countries. Because the lines were received late, they had to be planted under paddy conditions. For the introduction nursery, a paddy irrigation treatment was also practiced.

RESULTS AND DISCUSSION:

In the 1981 advanced cultivar experiment, cv. IV 404 had the best general appearance, and production averaged 455 gm/plot (6100 kg/ha, Table 1) for the paddy treatment. Yields were the highest for IV 404 under the paddy, 3-day, and 6-day treatments compared with the same treatments for the other cultivars. The average yield decrease was 12% from the flood to 3-day frequency, and 55% from the flood to the 6-day frequency for IV 404. Production was also good for the flood and intermittent irrigation treatments for cv. IR 22, TI, Chen Chun Ya, and IR 442-2-58. After years of testing and selection, most of the lines in the advanced cultivar experiment had Julian heading dates ranging from 217 to 228. Only 10 entries had heading dates other than within this fairly narrow range. Although we have attempted to select short-season types for an arid environment, only four lines in the present advanced cultivars experiment were earlier than 217 days. In some cases, we have retained border-line cultivars that were early, but they almost always had to be discarded in the following year's testing. Therefore, full season rice cultivars appear to have the greatest potential for rice production in a high-temperature environment.

For the cultivars (IR 22, IV 213, IV 330-1, IV 404, TI, and IR 1108-3-5-3-2) where the seeds produced from the flood, 3-day, and 6-day treatments have been kept separate, it appears that production in the 1981 crop year was affected somewhat by the source of seed from previous years. A small yield advantage occurred by planting seed from the paddy condition. Possibly, the smaller seed size (wt. per 1000 seeds) from the drier treatment may affect plant growth and lower rice seed production. However, it was difficult to see if there was a general genetic shift that resulted from planting seed from drier treatments. Some type of change seems to have occurred in IR 22 (entries #4 and #5), TI (entry #18), and perhaps others. The shift in growth characteristics for these lines appears to be toward earlier maturity and lower production. If there has been a change in plant type, it may have resulted from a random increase of similar appearing off-type plants rather than a natural elimination of poorer types and an increase of the stronger, more adapted types. Seed production is often very low in the drier treatments, and a random increase of the below standard genotypes could result from the seed mixture. At this time, the most reasonable conclusion is that the use of natural selection from the 3- and 6-day irrigation treatments for the improvement of more adaptable cultivars to an arid environment would be ineffective, but more definitive tests are needed.

The overall effect of irrigation treatments on the plant characteristics measured in the advanced cultivars experiment (Table 1) followed the trends reported in previous years. The values for general appearance, heading date, panicle exsertion, percent panicle sterility, and percent blanking increased as reduced amounts of water were applied. On the other hand,plant height, lodging, seed weight, and yield decreased with the drier treatments. Panicle exsertion had only a small change, but there seems to be a definite trend towards higher scores or a tendency for the panicles to remain further into the boot as less water was applied.

Data obtained on the new cultivar experiment are shown in Table 2. The main criteria that was used to determine which entries should be saved or discarded were general appearance and percent sterility. Yield was also an indication, but probably not the deciding factor, since the entries were not replicated. Interesting to note was that of the 29 new lines (not counting the 7 check cultivars) all except 3 had heading dates in the paddy (flood) treatment within the 217 to 228 Julian date range previously described, and 2 of these lines missed this range by only one day. The single remaining new line was a late maturing cultivar. Apparently, there is a tendency for rice cultivars to perform well under a narrow range of climatic conditions in the southwestern United States. Of these 29 new cultivars (checks excluded), only 9 appeared to perform well enough to be placed in the 1982 advance cultivar experiment. The remainder were discontinued, and the excess seed was sent to the USDA World Rice Collection Nursery in Beltsville, MD.

Data from the third experiment on natural selection is shown in Table 3. As explained earlier, genetic changes were not apparent from seeds produced under the intermittent irrigation treatments (3- and 6-day frequencies compared with the flood practice. A slight shift in plant characteristics was apparent for some entries such as IR 1108-3-5-3-2 (entries #22, #28, and #29); however, with some entries like IR 22 (entry #8), the general appearance and percent sterility appeared to be incorrect. As explained earlier, a random increase of the below standard genotypes could possibly result from the drier irrigation treatments.

From the 1981 USDA World Rice Collection Nursery (fourth experimental area), 32 cultivars were selected from the 1,119 lines planted. The number of selections saved and the country or program from which they originated were: 1, Japan; 5, Phillippines; 20, International Rice Research Institute; and 6, unknown origin.

Data for the 1982 experiments are only partially available and are still being analyzed. All aspects of the field investigations proceeded well during the early part of the season, but birds invaded the plots as soon as the early-maturing cultivars were in the milk stage. The earliest lines and, especially, one corner of the field were damaged most. The problem was finally controlled by saturating the plots with bird alarms and cannons. Bird damage notes were taken on all lines, and it appears that the yield information on plots with little or no bird damage might be useful. Data should be available on all plots in the previously measured plant characteristics except blanking and some yields. The greatest damage occurred on the flood treatments. Some of the older lines such as IV 213 and M7 were discarded in the 1982 advanced cultivar experiment since better lines have been selected. At present, seed is being processed, and data are being compiled and processed for the five experiments conducted at El Centro.

Yuma, Arizona

Field Procedures:

Six rice cultivars (IV 404, IR 22, IR 1108-3-5-3-2, RAX 2404, PI 433-220, and PI 432-560) were planted and irrigated on April 9, and six rice cultivars (IV 404, IR 22, IR 1108-3-5-3-2, RAX 2404, PI 433-220, and PI 324-462) were also planted on May 7. Ring Around Research [1/] furnished the seed for the RAX-2404 hybrid. Because of a shortage of seed supply, the sixth variety was different between the two planting dates. Each cultivar was replicated four times within each irrigation treatment. The drilling rate was about 56 kg/ha (50 lbs/acre), and the rows were spaced 18 cm (7 in.) apart. Eight irrigation treatments, as listed in Table 4, were begun shortly after the rice germinated. These treatments were based on the different stages of plant growth, i.e., irrigation initiated on June 1 coming before tillering, on July 1 coming before early panicle initiation, on August 15 coming before heading, and on October 1 before maturity.

Within these irrigation treatments, two water qualities were used including Colorado river water on treatments T_1 and T_2, and groundwater on treatments T_3, T_4, T_5, T_6, T_7, and T_8 (Table 4). The average total dissolved solids for the Colorado river water was about 900 mg/ℓ (1.4 decisiemens/m) as measured on 37 selected dates, and the average for the groundwater was about 1600 mg/ℓ (2.5 decisiemens/m) as measured 64 times during the growing season. The groundwater well was over 30 m (100 ft) deep and perforated the full depth. The suction line on the portable centrifugal pump was set at 6 m (20 ft) from the surface, and the static water table depth was about 1.8 m (6 ft). Periodically, soil samples were collected from the different plots and analyzed for soil salinity.

A preplant application of Ordram herbicide was not used in 1982; however, post-emergence applications of Ordram (molinate, S-Ethyl hexadydro-1-H-azepine-carbothioate) and Stam M-4 (propanil, 3', 4'-Dichlorophenyl-propionanilide) were used for control of grasses and weeds. Nitrogen fertilizer in the form of urea was broadcast and incorporated before planting at 56 kg/ha (50 lbs/acre) of N, followed by another 56 kg/ha after tillering and before initial heading. A listing of the dates where the different cultural practices occurred on the two planting dates is also given in Table 4.

Leaf analysis for N and P at 50, 65, and 80 days after planting were made for cv. IV 404 and irrigation treatments T_2 and T_7. Only one

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1/ Ring Around Research, Southeast Texas Research Station, P. O. Box 810, East Bernard, Texas, 77436. Mention of Company or proprietary name does not constitute an endorsement by the U. S. Department of Agriculture.

cultivar and two treatments were selected because data from the previous year showed little differences between cultivars or irrigation regimes. Later in the season at tillering, flowering, and harvest, a more complete nutrient analysis was made on the rice straw, panicle, and grain, as suggested by DeDatta (1981). Irrigation water applications were measured with a 10-cm (4-in.) propeller-type water meter, and detailed rice phenology was recorded on all plots. The rice was harvested when an entire planting date reached maturity, and yields were based on a 2.7 m^2 (29.2 ft^2) sampling area.

In addition to the intermittent irrigation experiment, an observational nursery of 48 cultivars and a herbicide trial with 4 cultivars was also conducted. There were 7 hybrid cultivars from Ring Around Research in the observational nursery. The herbicide trial included a post-emergence application of Stam M-4 in combination with four other herbicides - Modown (bifenox, Methyl 5-2, 4-dichlorophenoxy-2-nitrobenzoate), Prowl (N-1-ethylpropopyl-3,4-dimethyl-2,6-dinitrobenzenamine), Bolero (benthiocarb, S-4-chlorophenyl methyl diethylcarbamothioate), and Machete (butachlor, 2-chloro-2,6-diethyl-N-butoxy-methyl-acetanilide). Table 5 presents the rates and application dates for the herbicide trial. Irrigations were applied two times per week on the additional experiments. Yields were taken on the same size area for the observational nursery as the intermittent irrigation experiment. No yields were recorded on the herbicide test.

RESULTS AND DISCUSSION:

For both planting dates, the number of days from planting to emergence was 15 days (Table 4). Cool nighttime temperatures plus the need for frequent water applications has meant that germination has taken longer than most other crops planted at the same time. The slow early growth rate has also provided an opportunity for increased weed growth and has delayed the earliest date for herbicide applications. Barnyard and Mexican Sprangletop grasses were very difficult to control in 1982, and probably the worst infestation that we have encountered in four years of rice production. With the two applications of Stam M-4 made on the main irrigation experiment, some grasses were killed; however, others continued to grow and extensive hand weeding was required. The Stam M-4 appeared to do an excellent job in killing grass that was less than 6 leaves, but it was not effective in controlling Mexican Sprangletop. In the future for rice establishment and weed control, we plan to incorporate Ordram as a pre-emergence herbicide, to pre-irrigate the plots, to plant in a mulch or moist soil, and to apply Stam M-4 for post-emergence weed control. A small field test indicated that rice could be planted in this manner and result in better weed control. None of the herbicides used in combination with Stam M-4 gave any better weed control than Stam M-4 alone.

The seasonal water applied, precipitation, and pan evaporation for eight irrigation treatments planted two dates are presented in Tables 5 and 6. The seasonal total applications ranged from 384 to 199 cm (151 to 78 in.) for the T_7 compared to T_4 irrigation treatment for the April 9 planting date and from 325 to 179 cm (128 to 70 in.) for the same two extremes. The ratio of the seasonal water applied to Class A pan evaporation was about 2.2 and 1.2 for the wettest and driest treatments, regardless of the planting date. Twelve irrigations were applied to germinate and grow the rice until the first of July, when the plants were about 15 cm (6 in.) tall. This amounted to about 90 cm (3 ft) of water being applied for establishment. If the rice were planted in the mulch, the number and total amount of water applied could be greatly reduced during this period. Possibly, 6 irrigations or 45 cm (18 in.) of water would be adequate. After establishment, daily irrigations typically amounted to 2.5-3.8 cm (1-1.5 in.) per irrigation, whereas biweekly irrigations averaged about 6.4 cm (2.5 in.) per irrigation. With a planting date of mid-April and reduced water applications during early stages of plant growth, conceivably the irrigation water delivery could be less than 300 cm (10 ft) with daily irrigations from July through September, or less than 210 cm (7 ft) with biweekly irrigations for the same three-month period. If inexpensive, shallow groundwater was used, the difference between irrigating daily or twice a week may not be significant.

Figures 1 and 2 show the plant heights versus time for the six cultivars under the T_2 (biweekly irrigations from July through September with Colorado river water) and T_7 (daily irrigation from July through September using groundwater) irrigation treatments. Because the irrigation water applications were nearly the same until July 1, plant heights were not different between the eight irrigation treatments until mid-July. However, after maximum tillering, the daily-irrigated plots grew about 4 cm (1.5 in.) taller than the biweekly-irrigated plots. Plant heights were similar for the two planting dates, and cultivars PI 433-220 and PI 432-560 were about 5 cm (2 in.) taller than the other cultivars. Plant growth was not affected by irrigation water quality.

Average heading dates, final plant heights, panicle exsertion, percent lodging, stem angle, and yield for the six cultivars and eight irrigation treatments are presented in Tables 7 and 8 for the two planting dates, respectively. Heading was estimated when approximately 50% of the plants had exserted panicles, and most of the cultivars were heading during the month of September. The difference in heading between the planting dates was about a week compared with about 4 weeks between germination dates. The average heading date was September 7 (Julian date 250) for the April 9 planting date, and September 16 (Julian date 259) for the May 7 planting. Heading was generally earlier for the T_7 than the other irrigation treatments with most of the cultivars in the first planting date, but little difference in heading date was noted between irrigation treatments and cultivars in the second planting date. Panicle exsertion ranged from moderately-well exserted to just exserted for all cultivars, and stem angle was nearly erect for all cultivars with the exception of PI 324-462, which was only planted on the second date. Cultivar IR 22 was the least likely cultivar to lodge, while cv. PI 324-462 had the greatest lodging percent of the cultivars planted in the main plot. Cultivar RAX 2404 also showed some tendency to lodge. High winds on October 11 before harvesting the second planting date along with harvesting some of the cultivars a little after maturity may have caused some of the lodging.

Yields as shown in Tables 7 and 8 have been corrected for stands. The plant populations for cv. IV 404, IR 22, and IR 1108-3-5-3-2 were not as good for the April 9 planting date and also for cv. IV 404 on the May 7 planting date as the other cultivars. A combination of rice beards, planter adjustments, and early weed problems was the reason for the poorer stands. Mean grain yields were as high as 8500 kg/ha (7660 lbs/acre) for the RAX 2404 hybrid on the first planting date and a high of 7930 kg/ha (7080 lbs/acre) for the hybrid cultivar on the second planting date under the wettest T_7 irrigation regime. The following order, based on mean yields regardless of the irrigation treatment, resulted for the first planting date: (1) RAX 2404, 5600 kg/ha; (2) IV 404, 5026 kg/ha; (3) PI 433-220, 4867 kg/ha; (4) IR 22, 4598 kg/ha; (5) PI 432-560, 4372 kg/ha; and (6) IR 1108-3-5-3-2, 4148 kg/ha. Mean yields regardless of the irrigation regime for the second planting date were as follows: (1) RAX 2404, 5415 kg/ha; (2) PI 324-462, 4773 kg/ha; (3) IV 404, 4732 kg/ha; (4) PI 433-220, 4364 kg/ha; (5) IR 1108-3-5-3-2, 4359 kg/ha; and (6) IR 22, 4211 kg/ha. Although the earlier planting date gave a higher yield, this may not be significant for all years. Because heading dates were similar between the two planting dates, and because lower water applications are possible with the later planting date, our present recommendation is to plant rice between mid-April and early May at Yuma, Arizona. In terms of cultivars, the hybrid cultivar appears to have the greatest potential, whereas the other cultivars have similar yield possibilities. In 1983, cv. PI 433-220 will be dropped from the main study because of its dark colored grain, although the line was the third and fourth highest producer in the two planting dates. Grain types for all the cultivars ranged from medium to long with the longest grain rice coming from cv. 1108-3-5-3-2, PI 433-220, and PI 432-560.

As mentioned earlier, the 1982 rice production was the highest on the wettest T_7 irrigation treatment (daily irrigation from July through September using groundwater). However, the yield reduction from the wettest to driest tended to be less for the RAX 2404 hybrid than some of the other cultivars. The general order in terms of decreased production with irrigation treatment was as follows: T_7, T_6, T_5, T_8, T_1, T_2, T_4, and T_3 (see Tables 7 and 8). The T_6 and T_5 irrigation regimes were nearly the same, but the trend was that yields were higher for the daily irrigations from July 1 through August 15, during tillering and early panicle initiation, than from August 15 through September 30, during panicle development and heading. Also, indications were that the biweekly T_4 irrigations from July 1 to August 15 were slightly more beneficial than the biweekly T_3 irrigations from August 15 to September 30. There was not a significant difference in yield between T_8, T_1, and T_2, which verifies that the rice production was not changed by the two water qualities or the compaction of the soil surface.

Table 9 shows the results of periodic soil analysis. Some of the plots irrigated by groundwater had soil salinity levels equivalent to the Colorado river water, while other plots had soil salinity levels about one-half the total dissolved solids as the standard irrigation water. There appears to be no detrimental effect in yield or soil salinity for the plots irrigated with groundwater compared with those irrigated with the Colorado river water for the first year. The groundwater would not only provide an inexpensive water source, but groundwater pumping in some years could be beneficial in terms of water table control for other crops. The nutrient analyses of various plant parts are shown in Tables 10 and 11 for the two planting dates, respectively. The values for percent N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, Si, and Cl appear to be well within the adequate range listed by De Datta (1981, p. 365). The N, P, and K values were similar to last year's levels.

Yields from the observational nursery planted on the same two dates are found in Table 12. Most cultivars had a higher yield for the April 9 over the May 7 planting date, but there were exceptions. Uniformity in the plant populations may account for some of the same variability found in the main irrigation experiment. Generally, the hybrid cultivars were the highest yielding, and the order of highest to lower production in Yuma, Arizona, was as follows: RAX 2412, RAX 2414, RAX 2402, RAX 2416, RAX 2404, RAX 2406, and RAX 2408. This compared with the following order in El Centro, California, is as follows: RAX 2414, RAX 2416, RAX 2404, RAX 2408, RAX 2412, RAX 2408, and RAX 2402. Some of the other promising lines at Yuma in addition to those already used in the 1982 main irrigation experiment were KAR 27, KAR 30, PI 403, RP 7923, PI 432-566, IR 422-2-58, and IV 56. Thirty-three cultivars from the 1982 nursery were selected for planting in the 1983 observational nursery.

The 1983 main irrigation experiment will again consist of six cultivars, one planting date in mid-April, eight irrigation treatments, and two water qualities. Two hybrid cultivars, RAX 2404 and RAX 2414, will be used in the experiment. Additional hybrid rice cultivars will also be added in the nurseries at both the Yuma and El Centro locations.

SUMMARY AND CONCLUSIONS:

Four rice experiments were conducted in 1981 at the Imperial Valley Field Station, El Centro, California. In the main irrigation experiment, cultivar IV 404 was consistently the best performer, while some of the previouslly-selected cultivars, such as IV 213, were discarded. On all but a few improved selections, plant-water stress characteristics continued to be adversely affected by the 6-day irrigation frequency. Also, seeds collected from cultivars that formerly received less water tended to result in progeny of lower production. Some of the higher yielding cultivars besides IV 404 were IR 22, IR 1108-3-5-3-2, T1, PI 403-RP-1576, IR 442-2-58, PI 433-220, PI 432-560, and PI 324-462. Heading dates were very similar for the more promising lines, indicating that the longer season rice cultivars appear to have the greatest potential for rice production in an arid environment. In 1982, a special intermittent irrigation experiment, based on increasing water applications at specific stages of plant growth, was conducted along with the main irrigation experiment. A number of new hybrid and upland rice cultivars were included in other studies.

Three rice experiments were conducted in 1982 at the Yuma Valley Experiment Station, Yuma, Arizona. In the main study, six rice cultivars were planted on two dates and irrigated using eight irrigation treatments and two water qualities. The irrigation treatments included different intervals between water applications based on plant growth and phenology, and the water qualities were Colorado river water with about 900 mg/ℓ (1.4 dicisiemens/m) of total dissolved solids and groundwater pumped from a shallow water table with about 1600 mg/ℓ (2.5 decisiemens/m) of water salinity. All the following seven cultivars showed considerable promise: IV 404, IR 22, IR 1108-3-5-3-2, RAX 2404, PI 433-220, PI 432-560, and PI 324-462. Mean grain yields were as high as 8580 kg/ha on the RAX 2404 hybrid, and yield reductions for the drier irrigation treatments were generally less for the hybrid cultivar. Since only a small yield difference was noted between the two planting dates, rice planting between mid-April and early May is presently recommended for the long-season cultivars. Yields were not affected by water quality, and no large increase in soil salinity was noted between the beginning and end of the growing season for the two water qualities. The use of the marginal groundwater could provide an inexpensive and plentiful water supply for the production of rice.

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ble nter at r rriga expe t-ad d cu rs, ed or 1, 1 (Julian date 1) at El Centro, California.

Cultivar & Entry No.	Source[1/] 1979	Source[1/] 1980	Irrigation Treatment[2/] 1981	General Appearance[3/]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4/]	Grain Type[5/]	Percent Lodging	Percent Sterile Panicles (white)	Percent Blanking	Wt. per 1000 Seeds[6/]	Percent Stem Angle[7/]	Yield in gm.[8/]
IR 22	F	F	F	3.8	228	82	5.0	3.0	5.0	1.8	20	21.7	3	497
(1)			3	3.0	241	65	4.3	3.0	0	0	36	25.2	3	390
			6	5.3	251	51	5.8	2.8	0	16.8	35	17.3	2	134
IR 22	F	3	F	3.3	223	80	4.0	3.0	8.8	1.8	26	19.5	2	388
(2)			3	3.8	235	63	5.0	3.0	0	0	10	18.7	3	364
			6	5.5	246	46	5.0	3.0	0	45.0	62	17.6	2	82
IR 22	F	6	F	3.5	229	75	3.8	3.0	2.5	1.3	29	25.2	3	519
(3)			3	3.5	241	63	4.0	3.0	1.7	0	8	20.2	3	421
			6	5.5	252	47	5.8	3.0	0	30.0	49	15.1	3	116
IR 22	F	3	F	5.5	218	69	5.5	2.5	6.3	22.5	43	--	1	388
(4)			3	4.8	226	57	6.0	2.3	0	13.5	41	18.1	1	192
			6	7.0	236	47	6.0	2.0	0	77.5	95	18.7	1	47
IR22	3	3	F	5.3	217	70	4.8	2.0	2.5	23.8	39	18.2	2	372
(5)			3	4.5	226	55	4.8	2.8	0	7.5	37	17.9	2	250
			6	7.0	235	46	6.0	2.0	0	80.0	97	17.6	1	14
IV 213	6	6	F	5.5	217	67	4.5	2.3	5.0	15.0	63	--	1	354
(6)			3	5.8	226	52	5.8	2.5	0	15.0	42	20.6	1	138
			6	7.0	235	46	6.0	2.0	0	80.0	92	19.0	1	20
IV 404	F	F	F	2.5	228	81	3.0	3.0	2.5	0	18	21.9	3	477
(7)			3	3.0	235	62	4.3	3.0	0	0	10	20.0	3	378
			6	4.3	249	48	5.8	3.0	0	6.8	47	19.5	3	191
IV 404	3	3	F	2.5	226	74	3.0	3.0	2.5	0	17	21.6	3	466
(8)			3	3.0	236	64	3.0	3.0	0	0	19	20.4	3	433
			6	4.3	247	50	5.0	2.8	0	4.0	46	18.8	3	220
IV 404	6	6	F	2.3	223	76	3.0	3.0	2.5	0	18	23.0	2	423
(9)			3	2.8	235	65	5.0	3.0	0	0	21	19.1	3	384
			6	4.0	246	51	5.3	3.0	0	4.8	54	16.9	3	195
M 7	PR	F	F	6.8	218	81	1.5	2.3	2.5	80.0	78	--	1	244
(10)			3	6.8	225	61	2.0	2.3	0	68.3	71	22.8	1	104
			6	6.8	238	45	5.3	2.3	0	50.0	43	17.8	3	26

Table 1. (Continued)

Cultivar & Entry No.	Source[1/] 1979	Source[1/] 1980	Irrigation Treatment[2/] 1981	General Appearance[3/]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4/]	Grain Type[5/]	Percent Lodging	Percent Sterile Panicles (white)	Percent Blanking	Wt. per 1000 Seeds[6/]	Percent Stem Angle[7/]	Yield in gm.[8/]
M 7	PR	3	F	6.5	217	81	1.8	2.3	3.3	66.3	56	--	1	224
(11)			3	7.0	224	63	1.0	2.0	0	77.5	74	18.7	1	31
			6	7.8	236	41	4.3	2.8	0	63.8	99	--	2	3
M 7	PR	6	F	7.0	218	81	1.5	2.0	0	85.0	58	--	1	186
(12)			3	7.0	224	63	1.0	2.0	0	62.5	90	18.6	3	48
			6	8.0	237	34	5.3	2.0	0	78.8	100	--	1	0
IV 213	PR	F	F	5.3	217	69	5.0	2.5	2.5	41.8	45	--	1	321
(13)			3	5.3	225	56	5.0	2.5	0	10.0	33	21.5	2	221
			6	6.8	234	44	6.0	2.0	0	72.5	100	18.6	1	8
IV 213	PR	3	F	6.3	218	71	5.5	2.5	2.5	37.5	37	--	2	338
(14)			3	4.8	225	58	4.8	2.5	0	40.0	41	18.3	1	235
			6	6.8	235	45	6.0	2.3	0	78.8	97	16.8	1	6
IV 213	PR	6	F	5.3	217	69	4.8	2.3	2.5	40.0	39	--	1	350
(15)			3	5.8	225	56	5.0	2.5	0	16.7	41	20.3	2	209
			6	7.0	235	46	6.0	2.0	0	80.0	98	--	1	0
T 1	F	F	F	5.8	227	77	3.0	3.0	0	12.5	40	20.4	2	417
(16)			3	3.8	241	62	4.0	3.0	1.7	2.3	18	19.4	3	335
			6	5.3	253	53	5.3	3.0	0	6.8	23	16.7	2	183
T 1	3	3	F	4.0	226	76	3.0	3.0	0	4.0	49	--	3	477
(17)			3	4.0	238	64	4.0	3.0	2.5	3.5	32	21.1	3	389
			6	5.5	251	49	5.0	3.0	0	15.0	43	16.5	1	169
T 1	6	6	F	4.8	219	66	5.3	1.8	1.3	3.5	25	--	3	395
(18)			3	5.3	232	53	5.5	2.3	0	1.0	35	19.8	3	217
			6	6.0	244	45	6.0	1.8	0	23.8	76	14.9	3	28
Chen Chun			F	4.0	212	69	6.0	2.0	15.0	1.3	30	20.1	4	414
Ya (19)			3	4.5	222	53	5.5	1.8	0	2.3	26	18.5	4	329
			6	4.8	230	46	6.0	2.0	0	4.8	37	15.5	3	133
T 181			F	5.0	233	91	1.0	1.8	6.3	2.5	58	--	1	350
(20)			3	5.8	238	76	1.0	1.3	[illegible]	27.5	[illegible]	20.6	1	[illegible]
			6	5.3	256	51	5.8	2.3	0	6.3	43	19.3	2	72

Table 1. (Continued)

Cultivar & Entry No.	Source[1] 1979	Source[1] 1980	Irrigation Treatment[2] 1981	General Appearance[3]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4]	Grain Type[5]	Percent Lodging	Percent Sterile Panicles (white)	Percent Blanking	Wt. per 1000 Seeds[6]	Percent Stem Angle[7]	Yield in gm.[8]
IR 442-			F	4.8	232	82	6.3	2.5	2.5	4.8	25	21.9	3	580
2-58			3	4.3	247	73	6.0	3.0	0	3.3	11	21.8	3	527
(21)			6	5.8	266	56	6.0	3.0	0	11.8	30	15.6	3	185
IR 1108-	F	F	F	5.0	221	77	3.0	3.0	5.5	10.0	44	21.5	1	430
3-5-3-2			3	3.8	229	61	4.3	3.0	0	4.0	27	19.7	2	336
(22)			6	6.0	242	47	5.5	2.8	0	36.3	54	17.9	1	98
IR 1108-	3	3	F	5.5	220	74	4.0	3.0	3.8	6.3	56	21.1	2	358
3-5-3-2			3	4.0	228	64	3.5	3.0	0	5.7	36	19.4	2	335
(23)			6	6.3	240	48	5.5	3.0	0	46.3	57	18.8	1	97
IR 1108-	6	6	F	4.8	222	76	4.8	3.0	1.3	4.3	40	—	3	468
3-5-3-2			3	3.3	231	61	3.0	3.0	0	1.7	6	22.0	3	431
(24)			6	5.3	243	52	5.3	3.0	0	8.8	20	16.2	1	165
IR 1168-			F	4.5	235	85	3.0	3.0	2.5	2.5	34	—	1	464
24-2-1-31			3	3.8	242	76	3.8	3.0	2.5	2.5	14	20.4	1	326
(25)			6	6.0	267	53	5.8	2.3	0	9.3	56	23.3	2	89
IR 2153-			F	3.3	227	73	4.3	3.0	3.8	0	11	—	3	447
26-3-5			3	3.0	244	63	4.0	3.0	0	0.7	11	17.1	3	320
(26)			6	5.0	264	51	5.5	3.0	0	4.3	46	14.0	3	86
PI 324,			F	5.8	212	61	4.8	1.0	10.0	5.0	31	21.9	4	396
462			3	4.5	223	49	4.5	1.0	0	2.3	26	21.0	4	281
(27)			6	5.8	235	38	5.3	1.0	0	12.5	52	20.6	3	104
PI 433,		1625	F	4.3	236	79	5.0	3.0	5.0	2.5	17	22.5	2	542
220			3	3.5	250	67	5.5	3.0	0	0	18	19.0	3	464
(28)			6	5.3	272	48	6.0	3.0	0	3.5	68	16.2	3	117
PI 432,		1636	F	3.5	236	82	4.8	3.0	5.0	0	8	21.2	3	558
560			3	3.0	246	69	4.8	3.0	1.7	0	18	19.6	2	478
(29)			6	5.0	264	53	6.0	3.0	0	6.3	28	13.3	3	109
PI 432,		1640	F	3.3	222	69	5.5	3.0	3.8	3.0	36	24.1	3	321
564			3	3.8	235	54	5.5	3.0	1.7	0	15	20.8	3	217
(heat tol)			6	5.0	245	48	6.0	3.0	0	6.3	71	17.9	3	85
(30)														

Table 1. (Continued)

Cultivar & Entry No.	Source[1/] 1979	Source[1/] 1980	Irrigation Treatment[2/] 1981	General Appearance[3/]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4/]	Grain Type[5/]	Percent Lodging	Percent Sterile Panicles (white)	Percent Blanking	Wt. per 1000 Seeds[6/]	Percent Stem Angle[7/]	Yield in gm.[8/]
PI 432,		1642	F	4.3	213	73	4.8	2.5	10.0	6.3	17	20.4	2	362
566			3	4.5	225	56	5.8	3.0	3.8	0	27	22.7	3	151
(heat tol)			6	5.8	238	45	5.5	2.3	0	26.3	73	12.9	3	56
(31)														
IKAN	151	5007	F	4.5	210	62	3.5	1.0	18.8	2.5	20	19.6	5	460
Poochee			3	4.0	221	50	5.3	1.0	0	2.3	10	17.8	4	315
(Tai)			6	5.8	234	39	5.5	1.0	0	16.3	58	15.4	3	87
(32)														
Kar 27	989	5005	F	4.0	217	61	5.5	2.0	2.5	10.0	39	--	3	285
(Korea)			3	4.0	230	53	5.0	2.8	0	0	33	19.7	3	245
(33)			6	5.8	239	38	5.8	2.3	0	17.5	87	20.1	3	81
Kar 30	990	5022	F	5.0	217	61	4.0	2.3	6.3	15.5	35	--	3	267
(Korea)			3	4.3	225	46	5.0	2.3	0	0	28	18.2	3	211
(34)			6	6.0	239	35	6.0	2.5	0	12.5	44	19.9	3	80
IR 528	1383	5021	F	4.3	217	63	6.5	3.0	33	0.5	22	--	3	350
PK 13			3	3.8	227	54	6.0	3.0	0	0	39	20.2	3	254
(35)			6	4.8	240	44	6.0	2.3	0	4.8	84	17.7	3	78
Hz Ros	1384	5002	F	3.0	221	68	6.3	3.0	45.0	1.3	22	21.2	3	281
637 (Pak)			3	3.5	229	57	6.0	3.0	0	0	33	21.2	3	349
(36)			6	4.5	243	46	6.0	2.8	0	5.5	69	17.4	3	103
IR 1541	1555	5024	F	3.5	221	71	3.0	3.0	12.5	1.3	12	--	3	271
AF 28833			3	4.3	235	56	3.5	3.0	0	2.3	43	19.4	3	217
(37)			6	6.0	241	45	5.5	3.0	0	46.3	79	16.4	3	44
PI 402 RP	1575	5017	F	4.8	218	82	5.3	3.0	2.5	3.8	15	--	3	352
414 (Pak)			3	4.5	232	66	4.3	3.0	2.5	1.0	35	19.6	3	356
(38)			6	5.5	263	57	6.0	3.0	0	13.8	24	15.7	3	137
PI 403 RP	1576	5016	F	5.3	217	79	4.3	3.0	2.5	2.5	22	17.8	3	389
7923			3	4.3	234	65	3.5	3.0	0	1.0	39	18.6	3	377
(Pak)			6	5.8	261	57	6.0	3.0	0	11.8	17	14.2	3	165
(39)														
GID 72	4267	5065	F	5.8	217	70	5.0	2.5	3.8	32.8	36	--	2	354
(40			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			6	7.0	235	45	6.0	2.3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 1. (Continued)

Cultivar & Entry No.	Source[1/] 1979	Source[1/] 1980	Irrigation Treatment[2/] 1981	General Appearance[3/]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4/]	Grain Type[5/]	Percent Lodging	Percent Sterile Panicles (white)	Percent Blanking	Wt. per 1000 Seeds[6/]	Percent Stem Angle[7/]	Yield in gm.[8/]
IV 404-5	4328	5062	F	3.0	218	64	3.5	3.0	13.8	0.5	26	--	3	280
(41)			3	4.0	226	49	4.8	3.0	1.7	0.7	26	18.4	3	187
			6	4.8	233	39	6.0	3.0	0	14.3	81	17.7	3	74
IV 404-10	4318	5067	F	3.8	219	65	3.5	2.8	3.8	0.5	27	--	3	238
D 30 D			3	4.3	226	51	4.3	3.0	0	0	20	19.4	3	140
(42)			6	4.8	234	41	5.8	3.0	0	18.8	70	20.0	3	69
IV 213-		6032	F	6.3	218	71	5.8	2.0	0	43	38	--	1	300
12		7031	3	5.5	225	55	4.8	2.0	0	13.3	44	--	1	217
(43)			6	7.0	235	45	5.8	2.3	0	76.3	93	17.2	1	33
IV 404-		6007	F	4.8	222	78	4.0	3.0	6.3	5.5	40	20.0	2	401
8		7004	3	3.5	228	67	4.8	3.0	0	3.3	29	19.0	3	361
(44)			6	5.3	241	49	5.5	3.0	0	23.8	41	18.6	1	139
IV 213-		6006	F	5.8	217	70	5.5	2.3	2.5	37.5	35	--	2	394
8		7005	3	5.0	225	52	6.0	2.5	0	15.0	45	20.8	1	233
(45)			6	7.0	235	46	6.0	2.0	0	80.0	98	--	1	1
Pokkali	F		F	7.8	247	116	2.8	2.8	20.0	25.5	61	--	1	344
(46)			3	8.0	267	100	5.3	3.0	2.5	55.0	77	16.9	5	5
			6	8.0	288	73	6.0	3.0	1.3	85.0		--	3	0
M 101	Davis		F	6.5	194	63	2.5	2.0	0	40.0	41	--	1	159
(47)			3	7.3	200	45	3.8	2.3	0	62.5	97	15.0	1	4
			6	8.0	212	34	5.8	2.3	0	76.3	100	--	1	0
Calrose	F		F	6.8	217	75	2.3	2.0	1.3	82.5	78	--	1	178
76			3	7.0	223	52	1.0	2.0	0	62.5	97	14.4	1	23
(48)			6	7.8	232	33	5.0	2.0	0	70.0	100	--	1	0
Lobella	F		F	6.3	218	93	3.3	3.0	6.3	35.0	37	20.1	2	296
(49)			3	5.8	222	69	3.8	3.0	1.7	6.7	41	21.3	2	195
			6	7.0	226	50	5.8	3.0	1.3	36.3	91	16.7	2	14
Star-	F		F	7.8	222	100	1.0	3.0	1.3	92.5	90	16.9	1	112
bonnet			3	7.8	233	88	1.0	3.0	0	91.7	99	14.3	1	5
(50)			6	8.0	250	61	2.5	3.0	0	90.0	100	--	1	0

1/ Intermittent irrigation experiments with F = continuous flood; 3 and 6 = days between irrigations, respectively; PR = 1979 blanking study, or plot number from new cultivars or introductory nursery experiments in 1979 or 1980.

2/ F = continuous flood; 3 and 6 = days between irrigations, respectively.

3/ 1 = good; 5 = average; 9 = poor.

4/ 1 = well exserted; 3 = moderately well exserted; 5 = just exserted; 7 = partially exserted; 9 = enclosed.

5/ 1 = short; 2 = medium; 3 = long; 4 = extra long.

6/ Machine count.

7/ 1 = erect; 3 = intermediate; 5 = open; 7 = spreading; and 9 = procumbent.

8/ To convert yield to kg/hectare (lbs/acre) multiply by a factor of 13.4.

Table 2. Intermittent rice irrigation experiment - new cultivars, planted on May 1, 1981 (Julian Date 121) at El Centro, California.

Cultivar & Entry No.	Source 1/ 1980	Irrigation Treatment 2/ 1981	General Appearance 3/	Julian Heading Date	Ht. in cm.	Panicle Exsertion 4/	Grain Type 5/	Percent Lodging	Percent Sterile Panicles (white)	Percent Blanking	Wt. per 1000 Seeds 6/	Percent Stem Angle 7/	Yield in gm. 8/
Murasaki Inc.	339	F	5.0	271	104	6.7	3.0	0	1.7			1	437
Japan		3	7.3	278	70	6.0	2.7	0	6.7			1	9
(1)		6	no plant										
Milyang 23	482	F	4.7	220	72	4.7	3.0	5	0			1	319
Korea		3	4.7	229	51	5.3	2.7	0	3.3			3	168
(2)		6	5.7	241	46	6.0	3.0	0	20.0			3	54
Suweon 258	484	F	4.7	225	63	5.3	2.0	0	0	3	20.4	3	302
Korea		3	4.7	235	54	5.7	2.0	0	5.0	9		3	260
(3)		6	5.3	247	46	6.0	2.0	0	8.3	52		3	92
Nang Keng 33	500	F	3.0	228	75	3.7	2.0	0	0.7	24	24.0	2	477
China		3	3.7	237	59	5.0	2.0	0	0.7	35		3	352
(4)		6	5.0	254	49	5.3	1.7	0	6.7	48		3	121
IRRI 636, Dular	536	F	6.7	205	90	5.0	2.7	83	0			2	116
(heat tol.)		3	6.0	213	67	6.0	2.0	75	1.7			3	112
Phil.		6	6.0	227	74	6.0	2.7	8	8.3			3	47
(5)													
IRRI 47743		F	6.0	229	90	1.7	1.0	3.3	30.0			2	215
Trainung 67		3	7.3	240	81	1.0	1.7	0	41.7			1	39
Phil.		6	8.0	279	47	6.0	2.5	0	45.0			1	0
(6)													
Bala	718	F	5.3	219	67	5.0	1.7	11.7	1.7			3	291
India		3	5.3	232	57	3.7	1.7	0	5.0			3	185
(7)		6	6.3	250	45	5.3	2.0	0	50.0			2	1
Bharathy	720	F	3.7	226	78	6.0	3.0	5.0	5.0			3	429
India		3	4.0	239	60	5.7	3.0	0	1.7			3	321
(8)		6	6.0	256	54	6.0	3.0	0	26.7			2	91
Kiram	748	F	4.3	221	68	3.7	3.0	0	0	23	28.2	2	382
India		3	5.3	230	52	4.0	3.0	0	3.3	47		4	114
(9)		6	6.7	238	41	5.7	3.0	0	15.0	90		3	12
Giza 14	802	F	4.3	232	94	1.0	1.7	6.7	0.7			1	434
Egypt		3	6.0	236	83	1.0	1.3	5.0	13.3			2	161
(10)		6	7.3	250	50	3.7	2.0	0	80.0			1	23

Table 2. (Continued).

Cultivar & Entry No.	Source[1/] 1980	Irrigation Treatment[2/] 1981	General Appearance[3/]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4/]	Grain Type[5/]	Percent Lodging	Percent Sterile Panicles (white)	Percent Blanking	Wt. per 1000 Seeds[6/]	Percent Stem Angle[7/]	Yield in gm.[8/]
Giza 170	804	F	4.3	234	97	1.0	1.3	11.7	0			1	324
Egypt		3	6.3	239	86	1.0	1.7	8.3	48.3			2	97
(11)		6	7.0	246	48	2.3	1.7	0	68.3			1	0
Giza 172	806	F	3.7	233	94	1.0	1.3	6.7	1.7			2	350
Egypt		3	6.7	239	83	1.0	2.0	3.3	28.3			1	133
(12)		6	7.3	249	49	4.0	2.0	0	78.3			2	0
IR 1626-203	810	F	4.7	224	70	5.0	3.0	0	0			1	337
Egypt		3	4.0	239	61	3.7	3.0	0	0.7			2	256
(13)		6	6.3	257	47	5.7	3.0	0	30.0			1	49
IR 1416-131-		F	3.7	241	85	4.3	3.0	3.3	0.7			3	541
5-10-2		3	4.7	256	63	6.0	3.0	0	0.7			3	292
Phil.		6	7.0	285	44	6.0	2.7	0	58.3			2	55
(14)													
IR 5657-33-	854	F	4.7	229	88	3.7	3.0	1.7	0	22	28.1	3	359
2-1-2		3	4.0	243	70	3.7	3.0	0	0.7	16		3	310
Phil.		6	4.7	257	55	4.7	3.0	0	3.0	41		3	157
(15)													
Pusa 2-21	1042	F	4.0	225	76	4.3	2.0	5.0	0.7	26	18.4	3	331
(heat tol.)		3	4.3	234	61	3.7	2.3	0	2.3	49		3	258
Phil.		6	5.3	246	47	5.7	2.0	0	15.0	86		3	51
(16)													
ADT 1140,463	1052	F	5.3	219	66	5.3	2.0	3.3	13.3			2	228
(heat tol.)		3	6.3	230	49	5.7	2.0	0	15.0			3	122
Phil.		6	6.7	241	38	6.0	2.3	0	60.0			1	10
(17)													
IR 2006-P-	1060	F	3.3	223	68	4.3	3.0	0	0	22	26.5	2	319
12-3-2		3	3.7	234	53	5.3	3.0	0	0	36		3	227
(heat tol.)		6	4.0	249	46	6.0	3.0	0	5.0	63		3	88
Phil.													
(18)													
IR 3941-97-1		F	6.0	211	77	2.3	2.7	18.3	4.0			2	242
(heat tol.)		3	6.0	224	65	3.0	2.7	5.0	6.7			3	72
Phil.		6	6.7	235	45	4.7	2.3	0	60.0			2	35
(19)													
IR 9209-89-1-1	1065	F	4.7	216	64	6.0	3.0	30.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		3	4.7	225	47	5.7	3.0	0	1.7	33		3	194

Table 2. (Continued).

Cultivar & Entry No.	Source[1] 1980	Irrigation Treatment[2] 1981	General Appearance[3]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4]	Grain Type[5]	Percent Lodging	Percent Sterile Panicles (white)	Percent Blanking	Wt. per 1000 Seeds[6]	Percent Stem Angle[7]	Yield in gm.[8]
IET 4094	1083	F	3.3	236	80	3.7	3.0	11.7	0.7	21	16.8	3	417
(CR156-5021)		3	2.7	246	69	3.0	3.0	0	0	12		3	458
Phil.		6	5.3	264	52	6.0	3.0	0	6.7	56		3	107
(21)													
MRC 603-303	1089	F	4.3	222	67	3.0	3.0	3.3	0			2	311
Phil.		3	4.3	236	53	3.7	3.0	0	1.7			3	213
(22)		6	6.3	253	47	5.3	3.0	0	33.3			2	74
IR 4744-295-2	1118	F	3.0	222	73	3.0	3.0	20.0	0.7			2	266
Phil.		3	3.7	235	56	3.0	3.0	0	0			3	183
(23)			5.7	253	47	5.0	3.0	0	8.3			1	71
BG 402-4	1123	F	3.0	228	81	3.0	3.0	1.7	0.7			2	306
Phil.		3	3.0	240	67	3.0	3.0	0	0			3	273
(24)		6	6.0	258	53	5.0	3.0	0	43.3			1	68
PI 442-135	1173	F	4.7	234	97	1.0	1.7	5.0	1.7			1	376
Phil.		3	7.0	239	82	1.0	1.7	5.0	50.0			1	108
(25)		6	7.0	253	52	3.7	2.0	0	66.7			1	7
Noidware	5011	F	6.0	194	66	5.7	2.0	55.0	0			2	135
China		3	5.7	201	41	5.3	2.3	5.0	26.7			3	35
(26)		6	5.7	208	34	6.0	2.3	0	6.7			4	15
Chu Chin Isao	5049	F	5.7	194	57	4.3	2.3	40.0	1.7			2	139
China		3	6.0	201	44	4.7	2.7	0	8.3			2	71
(27)		6	5.7	212	36	6.0	2.3	0	23.3			2	37
Kar 398	5037	F	4.3	218	62	5.7	2.7	1.7	2.3	40	23.9	3	195
Korea		3	4.3	229	48	4.3	3.0	0	3.0	21		3	188
(28)		6	5.7	246	37	6.0	2.0	0	15.0	63		3	90
PI 362 S1364	5004	F	4.3	216	67	4.3	3.0	3.3	3.3			2	205
PK		3	4.3	225	50	5.0	3.0	0	2.3			2	174
(29)		6	5.7	244	46	5.7	3.0	0	18.3			3	23
Pokkali	F	F	7.0	248	122	6.0	3.0	8.3	2.0	54		1	276
(30)		3	8.0	264	97	6.0	2.7	0	71.7	66		3	43
		6	8.0	288	75	6.0	3.0	1.7	83.3	31		3	0

Table 2. (Continued).

Cultivar & Entry No.	Source[1] 1980	Irrigation Treatment[2] 1981	General Appearance[3]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4]	Grain Type[5]	Percent Lodging	Percent Sterile Panicles (white)	Percent Blanking	Wt. per 1000 Seeds[6]	Percent Stem Angle[7]	Yield in gm.[8]
Starbonnet	F	F	8.0	223	97	1.7	3.0	0	93.3	86		1	88
(31)		3	8.0	233	83	1.0	3.0	0	91.7	99		1	1
		6	8.0	253	61	3.7	3.0	0	90.0	100		1	0
Starbonnet		F	8.0	222	96	2.3	3.0	0	91.7	93		1	70
(32)		3	8.0	234	84	2.3	3.0	0	91.7	96		1	63
		6	7.7	253	61	4.7	3.0	0	90.0	94		1	0
M101		F	6.3	197	66	2.3	2.0	0	31.7	23		1	154
(33)		3	7.0	201	44	2.0	2.3	0	80.0	91		1	13
		6	8.0	209	35	5.3	2.7	0	71.7	91		1	0
Calrose 76		F	6.3	217	79	2.3	2.0	3.3	38.3	67		1	169
(34)		3	7.0	222	54	2.3	2.0	0	68.3	94		1	22
		6	8.0	233	34	5.7	2.0	0	71.7	68		1	0
IR 22	3	F	3.7	226	77	5.3	3.0	1.7	0	29		2	500
(35)		3	3.3	228	60	3.7	2.3	0	0	30		3	345
		6	5.7	242	46	5.3	2.6	0	31.7	70		2	94
IV 404	3	F	3.0	224	81	3.7	3.0	1.7	0	27		3	416
(36)		3	3.3	237	61	4.3	3.0	0	0	30		3	350
		6	4.0	248	49	5.7	3.0	0	4.0	41		3	174

1/ Intermittent irrigation experiments with F = continuous flood and 3 = days between irrigations; or plot numbers from new cultivars or introductory nursery experiments in 1980.

2/ F = continuous flood; 3 and 6 = days between irrigations, respectively.

3/ 1 = good; 5 = average; 9 = poor.

4/ 1 = well exserted; 3 = moderately well exserted; 5 = just exserted; 7 = partially exserted; 9 = enclosed.

5/ 1 = short; 2 = medium; 3 = long; 4 = extra long.

6/ Machine count.

7/ 1 = erect; 3 = intermediate; 5 = open; 7 = spreading; and 9 = procumbent.

8/ conve eld /hec (lbs) mul by tor .4.

Table 3. Intermittent rice irrigation experiment - natural selection, planted on May 1, 1981 (Julian Date 121) at El Centro, California.

Cultivar & Entry No.	Source[1/] 1979	Source[1/] 1980	Irrigation Treatment[2/] 1981	General Appearance[3/]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4/]	Grain Type[5/]	Percent Lodging	Percent Sterile Panicles (white)	Percent Stem Angle[6/]	Yield in gm.[7/]
IR 22	F	F	F	4.0	230	82	3.7	3.0	3.3	0.7	3	529
(1)			3	3.0	240	62	4.3	3.0	0	0	3	354
			6	5.0	259	51	5.7	2.7	0	13.3	2	97
I 22	F	3	F	3.0	255	81	5.0	3.0	5.0	0.7	3	591
(2)			3	3.0	239	57	4.3	3.0	0	0	3	333
			6	5.0	258	50	6.0	3.0	0	10.0	2	112
IR 22	F	6	F	3.0	223	77	4.3	3.0	0	0	2	533
(3)			3	3.7	236	60	5.7	3.0	0	0.7	3	337
			6	6.0	249	49	6.0	2.7	0	36.7	2	57
IR 22	3	F	F	3.0	225	77	3.7	3.0	1.7	0	3	614
(4)			3	3.7	236	61	3.7	3.0	0	0.7	3	343
			6	5.0	252	50	5.3	3.0	0	6.7	3	91
IR 22	3	3	F	3.7	230	78	3.7	3.0	1.7	1.3	3	611
(5)			3	3.0	239	61	5.0	3.0	0	0.7	3	340
			6	5.7	259	48	6.0	3.0	0	21.7	2	73
IR 22	3	6	F	3.0	254	80	6.0	3.0	3.3	0.7	3	651
(6)			3	3.0	237	57	5.7	3.0	0	0	3	303
			6	5.0	254	51	6.0	3.0	0	21.7	2	103
IR 22	6	F	F	3.0	227	75	5.3	3.0	3.3	0	3	582
(7)			3	3.3	238	58	4.7	3.0	0	0.7	3	232
			6	5.3	258	50	5.7	3.0	0	40.0	3	74
IR 22	6	3	F	4.0	223	75	3.7	2.7	1.7	51.0	2	464
(8)			3	4.3	226	54	3.7	2.7	0	26.7	2	221
			6	5.3	254	49	5.7	3.0	0	33.3	3	80
IR 22	6	6	F	3.3	226	80	5.3	3.0	5.0	0.7	3	574
(9)			3	3.0	239	61	4.3	3.0	0	0	3	323
			6	5.3	257	50	6.0	3.0	0	20.0	2	81
IR 213	F	F	F	5.0	218	70	4.3	2.3	1.7	23.3	1	439
(10)			3	5.0	225	54	5.0	2.3	0	10	1	183
			6	7.0	241	44	6.0	2.0	0	78.3	1	0

Table 3. (Continued).

Cultivar & Entry No.	Source[1/] 1979	Source[1/] 1980	Irrigation Treatment[2/] 1981	General Appearance[3/]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4/]	Grain Type[5/]	Percent Lodging	Percent Sterile Panicles (white)	Percent Stem Angle[6/]	Yield in gm.[7/]
IV 213	F	3	F	5.3	217	70	4.7	2.7	0	28.3	1	441
(11)			3	5.0	228	57	5.7	2.7	0	19.0	2	217
			6	7.0	236	43	6.0	2.0	0	80.7	1	1
IV 213	F	6	F	5.7	218	69	5.0	2.0	0	50.0	1	439
(12)			3	5.3	227	55	6.0	2.7	0	21.7	1	151
			6	6.3	239	44	6.0	2.0	0	76.7	1	5
IV 213	3	F	F	5.3	217	69	5.3	2.7	0	33.3	1	437
(13)			3	5.3	226	54	5.7	2.7	0	13.3	1	164
			6	6.3	239	44	6.0	2.3	0	76.7	1	5
IV 213	3	3	F	6.0	217	71	5.3	2.7	0	58.3	2	390
(14)			3	5.3	228	52	5.7	2.3	0	8.3	2	167
			6	7.0	239	43	6.0	2.0	0	80.0	1	0
IV 213	3	6	F	5.3	220	64	5.3	2.7	0	25.7	1	360
(15)			3	5.7	227	54	5.7	2.7	0	28.3	1	157
			6	6.7	243	44	6.0	2.0	0	70.0	1	14
IV 213	6	F	F	4.7	217	73	5.3	2.3	1.7	28.3	1	468
(16)			3	5.7	226	55	5.7	2.3	0	26.7	2	133
			6	7.0	238	45	6.0	2.3	0	76.7	1	13
IV 213	6	3	F	5.0	217	70	4.7	2.7	0	36.7	2	441
(17)			3	5.3	227	52	5.7	2.3	0	18.3	1	148
			6	7.0	243	46	6.0	2.0	0	80.0	1	0
IV 213	6	6	F	5.7	217	70	6.0	2.7	0	50.0	1	452
(18)			3	5.3	227	54	5.3	2.0	0	13.3	2	158
			6	6.7	240	43	6.0	2.0	0	75.0	1	15
IV 213	PR	F	F	6.0	216	68	5.7	3.0	1.7	51.7	1	381
(19)			3	5.7	226	52	5.7	2.3	0	36.7	1	101
			6	7.0	238	44	6.0	2.0	0	78.3	1	1
IV 213	PR	3	F	5.7	217	68	5.0	2.3	0	41.7	2	373
(20)			3	6.0	266	52	6.0	[illegible]	0	[illegible]	1	[illegible]
			6	7.3	241	45	6.0	2.3	0	78.3	1	0

Table 3. (Continued).

Cultivar & Entry No.	Source[1/] 1979	Source[1/] 1980	Irrigation Treatment[2/] 1981	General Appearance[3/]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4/]	Grain Type[5/]	Percent Lodging	Percent Sterile Panicles (white)	Percent Stem Angle[6/]	Yield in gm.[7/]
IV 213	PR	6	F	5.7	218	70	5.7	2.3	0	51.7	1	401
(21)			3	6.3	226	51	6.0	2.0	0	36.7	1	103
			6	6.7	242	44	6.0	2.3	0	55.0	2	273
IR 1108-	F	F	F	5.0	221	81	3.7	3.0	0	5.7	3	502
3-5-3-2			3	3.3	237	63	5.3	3.0	1.7	2.0	3	354
(22)			6	5.3	244	51	5.7	2.7	0	18.3	2	129
IR 1108-	F	3	F	4.3	223	77	3.0	3.0	1.7	11.7	2	447
3-5-3-2			3	4.3	233	61	3.7	3.0	0	3.0	2	338
(23)			6	5.0	256	52	5.7	3.0	0	13.3	2	154
IR 1108-	F	6	F	5.3	223	76	3.7	3.0	1.7	15.0	2	453
3-5-3-2			3	3.7	231	62	5.0	3.0	0	4.0	3	262
(24)			6	5.3	261	49	5.3	3.0	0	28.3	1	146
IR 1108-	3	F	F	5.0	222	78	3.7	3.0	1.7	21.7	1	450
3-5-3-2			3	3.7	228	62	4.3	3.0	0	4.0	2	351
(25)			6	5.3	253	51	6.0	3.0	0	23.3	2	133
IR 1108-	3	3	F	5.3	219	74	5.0	2.7	0	31.7	1	424
3-5-3-2			3	4.3	232	58	5.0	3.0	1.7	3.0	3	288
(26)			6	6.0	244	49	5.7	2.7	0	45.0	1	107
IR 1108-	3	6	F	4.3	219	79	5.0	3.0	1.7	10.7	3	483
3-5-3-2			3	4.3	234	59	4.3	3.0	0	4.0	2	301
(27)			6	5.3	245	51	5.0	3.0	0	25.0	1	131
IR 1108-	6	F	F	4.3	233	80	2.3	3.0	1.7	11.7	2	444
3-5-3-2			3	3.3	240	61	4.3	3.0	0	2.3	3	354
(28)			6	5.0	260	52	5.7	3.0	0	10.0	2	163
IR 1108-	6	3	F	4.7	228	78	3.0	3.0	0	18.3	1	534
3-5-3-2			3	3.3	238	61	4.3	3.0	1.7	1.3	3	339
(29)			6	5.0	261	52	6.0	3.0	0	13.3	2	181
IR 1103-	6	6	F	4.0	223	77	4.7	3.0	1.7	20.0	2	497
3-5-3-2			3	4.3	232	60	4.3	3.0	0	3.0	3	303
(30)			6	5.7	250	50	6.0	2.7	0	31.7	2	99

Table 3. (Continued).

Cultivar & Entry No.	Source[1] 1979	Source[1] 1980	Irrigation Treatment[2] 1981	General Appear-ance[3]	Julian Heading Date	Ht. in cm.	Panicle Exsertion[4]	Grain Type[5]	Percent Lodging	Percent Sterile Panicles (white)	Percent Stem Angle[6]	Yield in gm.[7]
Calrose 76		CA	F	6.3	216	77	1.7	2.0	0	70.0	1	197
(31)			3	7.0	222	48	3.3	2.0	0	75.0	1	27
			6	8.0	237	36	5.7	2.0	0	58.3	1	0
M101		CA	F	6.0	195	62	1.7	2.3	0	53.3	1	204
(32)			3	6.0	213	51	5.0	2.3	0	50.0	2	119
			6	8.0	213	38	4.3	2.0	0	58.3	1	0
Starbonnet		AK	F	8.0	223	98	1.0	3.0	0	95.0	1	105
(33)			3	8.0	236	80	1.0	3.0	0	90.0	1	0
			6	8.0	256	61	3.0	3.0	0	90.0	1	0
IV 404	6	F	F	2.3	222	76	3.7	3.0	1.7	0	3	562
(34)			3	3.3	230	61	3.7	3.0	0	0	3	302
			6	4.0	247	51	6.0	2.7	0	5.7	2	159
T1		F	F	3.7	228	79	3.7	3.0	0	4.0	2	470
(35)			3	4.0	241	63	4.3	3.0	1.7	1.7	3	374
			6	5.0	257	50	5.7	3.0	0	21.7	2	115

1/ Intermittent irrigation experiments with F = continuous flood; 3 and 6 = days between irrigations, respectively; or state of origin.

2/ F = continuous flood; 3 and 6 = days between irrigations, respectively.

3/ 1 = good; 5 = average; 9 = poor.

4/ 1 = well exserted; 3 = moderately well exserted; 5 = just exserted; 7 = partially exserted; 9 = enclosed.

5/ 1 = short; 2 = medium; 3 = long; 4 = extra long.

6/ 1 = erect; 3 = intermediate; 5 = open; 7 = spreading; and 9 = procumbent.

7/ To convert yield to kg/hectare (lbs/acre) multiply by a factor of 13.4 (12).

Table 4. Irrigation treatments, cultivars, and cultural practices for the intermittent rice irrigation experiments planted on April 9 (Julian date 99) and May 7, 1982 (Julian date 127) at Yuma, Arizona.

Irrigation Treatment	Water Quality 1/ and Irrigation Frequency Date of Initiation			
	JUN 1	JUL 1	AUG 15	OCT 1
T_1	CR-Weekly	CR-Biweekly	CR-Biweekly	CR-Weekly
T_2	CR-Weekly	CR-Biweekly	CR-Biweekly	CR-Weekly
T_3	GW-Weekly	GW-Weekly	GW-Biweekly	GW-Weekly
T_4	GW-Weekly	GW-Biweekly	GW-Weekly	GW-Weekly
T_5	GW-Weekly	GW-Biweekly	GW-Daily	GW-Weekly
T_6	GW-Weekly	GW-Daily	GW-Biweekly	GW-Weekly
T_7	GW-Weekly	GW-Daily	GW-Daily	GW-Weekly
T_8	GW-Weekly	GW-Biweekly	GW-Biweekly	GW-Weekly

Entry No.	Cultivars Planting Date	
	APR 9	MAY 7
1	IV 404	IV 404
2	IR 22	IR 22
3	IR 1108-3-5-3-2	IR 1108-3-5-3-2
4	RAX 2404	RAX 2404
5	PI 433-220	PI 433-220
6	PI 432-560	PI 324-462

Cultural Practice	Application Rate	Planting Date	
		APR 9	MAY 7
Fertilizer			
Preplant	56 kg/ha	APR 8	MAY 6
Before Tillering	56 kg/ha	AUG 3	AUG 3
Weed Control			
Irrigation & Nursery			
Stam M-4	9.5 ℓ/ha	MAY 25	JUN 2
Stam M-4	14.0 ℓ/ha	JUN 14	JUN 15
Ordram	7.0 ℓ/ha	JUL 6	JUL 6
Herbicide Test			
Stam M-4 + Mowdown	9.5 ℓ/ha + 7.0 ℓ/ha	MAY 25	JUN 2
Stam M-4 + Prowl	9.5 ℓ/ha + 2.3 ℓ/ha		
Stam M-4 + Bolero	9.5 ℓ/ha + 1.2 ℓ/ha		
Stam M-4 + Machete	9.5 ℓ/ha + 7.0 ℓ/ha		
Plant Growth			
Germination		APR 23	MAY 21
Avg. Heading		SEP 7	SEP 16
Harvest		NOV 8	NOV 16

1/ CR = Colorado river water, 900 mg/ℓ; GW = groundwater, 1600 mg/ℓ.

Table 5. Summary of seasonal water applied, precipitation, and pan evaporation for eight irrigation treatments on rice planted April 9, 1982 at Yuma, Arizona.

Factor	Irrigation Treatment 1/ T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
Number of irrigations	36	37	33	31	58	53	73	37
Seasonal irrigation water applied (cm)	232	225	216	197	316	299	382	219
Avg. irrigation size (cm)	6.4	6.1	6.5	6.4	5.4	5.6	5.2	5.9
Seasonal precipitation (cm)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Seasonal total water applied (cm)	234	227	218	199	318	301	384	221
Seasonal pan evaporation (cm)	171	171	171	171	171	171	171	171

Table 6. Summary of seasonal water applied, precipitation, and pan evaporation for eight irrigation treatments on rice planted May 7, 1982 at Yuma, Arizona.

Factor	Irrigation Treatment 1/ T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
Number of irrigations	35	35	32	29	56	48	68	36
Seasonal irrigation water applied (cm)	204	207	198	177	312	273	323	212
Avg. irrigation size (cm)	5.8	5.9	6.2	6.1	5.6	5.7	4.8	5.9
Seasonal precipitation (cm)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Seasonal total water applied (cm)	206	209	200	179	314	275	325	214
Seasonal pan evaporation (cm)	147	147	147	147	147	147	147	147

1/ See Table 4 for description of irrigation treatments.

T[illegible] 7. [illegible]mitt[illegible] [illegible]ice [illegible]atio[illegible] [illegible]erim[illegible] [illegible]ante[illegible] Apri[illegible], 1982 [illegible]ian [illegible]99) a[illegible] [illegible]a, A[illegible]a.

Cultivar & Entry No.	Irrigation Treatment 1/	Julian Heading Date	Plant Ht. in cm.	Grain Type 2/	Panicle Exsertion 3/	Percent Lodging	Wt. per 500 Seeds in gm.	Stem Angle 4/	Yield in kg/ha
IV 404 (1)	T_1	246	71	4.5	5	10	12.1	1	4228
	T_2	250	64	4	5	20	12.4	1	4819
	T_3	259	53	3	5	3	11.7	1	3875
	T_4	256	61	3	5	5	9.7	1	3425
	T_5	250	71	5	5	3	10.1	1	6486
	T_6	250	66	4.5	5	3	10.9	1	5569
	T_7	246	71	4.5	5	18	11.3	1	7297
	T_8	250	61	4.5	4.5	3	11.2	1.5	4507
IR 22 (2)	T_1	250	71	4	5	0	11.8	1	5363
	T_2	250	64	4.5	5	0	9.2	1	5290
	T_3	259	51	3.5	5	0	9.6	1	2050
	T_4	256	51	4	5	0	8.1	1	2569
	T_5	256	74	5	5	0	9.8	2.5	6257
	T_6	256	66	4	5	3	9.9	1	4894
	T_7	250	74	3.5	5	0	10.8	1	6063
	T_8	250	61	4	4	0	9.2	2	4296
IR 1108-3-5-3-2 (3)	T_1	250	69	4	5	10	10.7	1	4159
	T_2	250	64	4	5	10	9.8	1	4399
	T_3	249	56	3.5	5	0	8.8	1	2636
	T_4	246	61	4	5.5	0	9.1	1	2709
	T_5	256	66	4	5	0	10.2	1	4469
	T_6	250	66	4	3.5	5	10.0	2.5	4672
	T_7	246	74	4	5	20	11.3	1	6276
	T_8	256	66	5	5	0	10.1	1	3865
RAX 2404 (4)	T_1	246	74	3.5	5	40	11.2	1	4548
	T_2	246	66	3.5	5	38	11.2	1.3	5154
	T_3	256	64	3.5	4.5	5	10.5	1.5	4521
	T_4	250	61	4	5	0	10.3	1	3512
	T_5	250	74	4.5	5	23	11.2	1	6393
	T_6	250	76	4	4	45	10.9	2	6698
	T_7	242	76	4	5	98	10.4	1	8578
	T_8	250	76	4.5	4.5	23	11.0	1.5	5401

Table 7. (Continued).

Cultivar & Entry No.	Irrigation Treatment[1]	Julian Heading Date	Plant Ht. in cm.	Grain Type[2]	Panicle Exsertion[3]	Percent Lodging	Wt. per 500 Seeds in gm.	Stem Angle[4]	Yield in kg/ha
PI 433-220 (5)									
	T_1	263	86	4	5	10	11.4	1	4200
	T_2	263	76	4	5	3	11.3	1	5212
	T_3	271	61	4	4.5	0	11.1	1.5	3142
	T_4	277	61	4.5	6	0	10.3	1	2364
	T_5	263	81	5	5	5	11.3	1	5272
	T_6	259	81	4.5	5	3	10.9	1	5273
	T_7	259	81	4.5	5	73	11.7	1	9007
	T_8	269	71	4.5	4.5	0	9.6	1.5	4463
PI 432-560 (6)									
	T_1	250	74	4	5	5	11.2	1	3674
	T_2	250	64	5	5	5	8.5	1	4552
	T_3	259	61	4	5	0	10.7	1	3213
	T_4	246	66	5	5	0	9.7	1	2281
	T_5	256	69	5	5	5	8.5	1	4318
	T_6	250	76	4.5	5	3	8.7	1	4900
	T_7	250	81	4	5	85	9.0	1	7286
	T_8	256	76	5	4.5	5	8.7	1.5	4155

1/ See Table 4 for description of irrigation treatments.

2/ 1 = pearl; 2 = short (5.5 mm or less); 3 = medium (5.51-6.6 mm); 4 = long (6.61-7.5 mm); 5 = estra long (>7.51 mm).

3/ 1 = well exserted; 3 = moderately well exserted; 5 = just exserted; 7 = partly exserted; 9 = enclosed.

4/ 1 = erect; 2 = angle is about 30° from perpendicular; 3 = angle is about 45° from perpendicular.

Table 8. Intermittent rice irrigation experiment planted on May 7, 1982 (Julian date 127) at Yuma, Arizona.

Cultivar & Entry No.	Irrigation Treatment1/	Julian Heading Date	Plant Ht. in cm.	Grain Type2/	Panicle Exsertion3/	Percent Lodging	Wt. per 500 Seeds in gm.	Stem Angle4/	Yield in kg/ha
IV 404 (1)	T_1	259	66	4	5	10	10.1	1	3566
	T_2	259	69	4	5	0	10.3	1	4656
	T_3	259	58	4.5	5	18	10.3	1	3367
	T_4	259	61	4.5	4.3	5	10.2	1.5	4929
	T_5	259	71	4	5	3	10.4	1	5598
	T_6	250	74	4	4.5	10	11.4	1.5	6026
	T_7	256	79	4	5	18	11.3	1	6438
	T_8	259	64	4	5	0	9.5	1	3275
IR 22 (2)	T_1	259	69	4	5	0	9.1	1	3213
	T_2	263	69	5	5	0	9.6	1	4820
	T_3	263	58	4.5	5.5	0	10.0	1	2678
	T_4	259	64	4	5	0	9.0	1	3347
	T_5	259	74	4.5	5	0	11.6	1	5155
	T_6	259	74	3.5	5	0	9.8	1	5144
	T_7	259	81	5	5	0	9.8	1	6153
	T_8	259	66	4	5	0	8.7	1	3175
IR 1108-3-5-3-2 (3)	T_1	259	66	4	5	0	9.5	1	3509
	T_2	259	66	5	5	10	9.8	1	4537
	T_3	259	61	4.5	5.5	0	9.5	1	2188
	T_4	256	66	4	5	0	9.5	1	3900
	T_5	259	74	4	5	30	10.1	1	5005
	T_6	259	76	4.5	5	23	10.3	1	6308
	T_7	256	65	5	4	25	10.3	2	5884
	T_8	259	69	4.5	5	0	9.2	1	3644
RAX 2404 (4)	T_1	259	81	4.5	5	35	12.1	1	4207
	T_2	259	81	4	5	43	10.8	1	4640
	T_3	259	69	4	5.5	3	9.3	1	4115
	T_4	259	71	3.5	4.5	8	10.2	1.5	4885
	T_5	256	74	5	5	73	10.9	1	5742
	T_6	256	84	4	4.5	78	11.2	1.5	7539
	T_7	256	89	5	4.5	80	11.1	1	7934
	T_8	256	71	4.5	5	5	9.2	1	4257

Table 8. (Continued).

Cultivar & Entry No.	Irrigation Treatment[1/]	Julian Heading Date	Plant Ht. in cm.	Grain Type[2/]	Panicle Exsertion[3/]	Percent Lodging	Wt. per 500 Seeds in gm.	Stem Angle[4/]	Yield in kg/ha
PI 433-220 (5)									
	T_1	277	81	5	6.5	0	10.7	1	3138
	T_2	277	86	5	7	0	10.9	1	6621
	T_3	278	69	4	6.5	0	11.9	1	1796
	T_4	278	76	4	5	0	10.3	1	3493
	T_5	270	76	4.5	6	0	10.6	1	5313
	T_6	263	94	5	5	0	10.8	1	5677
	T_7	263	97	5	5	3	11.0	1	6636
	T_8	278	76	4	7	0	9.3	1	2240
PI 324-462 (6)									
	T_1	242	76	3	5	90	10.2	1	4611
	T_2	237	74	3	5	100	10.7	1	5687
	T_3	237	58	3	4	63	9.0	2	3022
	T_4	263	69	3	3	43	9.6	3	4006
	T_5	242	74	3	5	55	12.7	1	4220
	T_6	237	81	3	3	100	12.2	3	6292
	T_7	237	81	3.5	3	88	10.7	3	6523
	T_8	242	69	2.5	5	58	11.8	1	3826

1/ See Table 4 for description of irrigation treatments.

2/ 1 = pearl; 2 = short (5.5 mm or less); 3 = medium (5.51-6.6 mm); 4 = long (6.61-7.5 mm); 5 = estra long (>7.51 mm).

3/ 1 = well exserted; 3 = moderately well exserted; 5 = just exserted; 7 = partly exserted; 9 = enclosed.

4/ 1 = erect; 2 = angle is about 30° from perpendicular; 3 = angle is about 45° from perpendicular.

Table 9. Soil analysis on rice irrigation experiment planted on April 9 (Julian date 99) and May 7, 1982 (Julian date 127) at Yuma, Arizona.

Irrigation Treatment	Planting Julian Date	Sampling Julian Date	Soil Depth, cm 0-5	0-30	30-60	60-90	Soil Depth, cm 0-5	0-30	30-60	60-90	Soil Depth, cm 0-5	0-30	30-60	60-90
			Total Dissolved Solids (mg/ℓ)				NO_3-N (mg/ℓ)				PO_4-P (mg/ℓ)			
T_2	99	215	915	973	979	710	5	8	7	10	2.8	1.6	1.5	1.1
T_7			1344	1037	1408	1946	86	40	42	25	3.0	2.3	1.3	1.3
T_2	127		1382	1325	1824	1261	8	45	40	32	3.0	0.9	0.6	1.0
T_7			1114	826	794	762	44	37	34	29	2.3	0.9	0.6	0.6
T_1	99	289	1357	723	563	678	26	62	118	86	1.3	0.4	0.4	0.4
T_2			1152	1280	742	960	27	80	82	25	2.4	1.0	0.9	0.4
T_3			1538	1024	832	768	23	64	30	22	1.6	0.6	0.6	0.6
T_4			2368	1152	2178	1152	36	50	27	28	2.8	0.8	0.5	0.5
T_5			1728	832	1218	1984	30	76	78	88	1.6	0.8	0.6	0.6
T_6			1408	960	1266	1408	22	8	42	52	2.1	0.6	0.3	0.3
T_7			1408	768	896	1664	6	12	24	27	2.1	0.3	0.2	0.2
T_8			1280	742	832	768	24	54	64	85	2.0	0.4	0.4	0.3
T_1	127	289	1024	1344	1152	220	104	162	82	46	1.9	0.8	0.6	0.4
T_2			614	578	526	600	48	34	30	42	1.6	0.4	0.3	0.3
T_3			860	550	371	230	62	23	25	32	1.4	0.2	0.2	0.2
T_4			934	723	710	768	58	23	27	33	2.3	0.8	0.6	0.6
T_5			1472	768	454	320	88	22	23	37	2.1	0.9	0.8	0.6
T_6			1152	960	1024	422	66	25	31	38	1.9	0.8	0.6	0.4
T_7			1538	832	742	630	58	18	23	43	1.8	0.6	0.3	0.3
T_8			1062	845	1408	578	74	42	85	86	2.0	0.6	0.3	0.3

ble 10. Plant nutrient analysis for cultivar IV 404 on the rice irrigation experiment planted on April 9, 1982 (Julian date 99) at Yuma, Arizona.

rigation eatment 1/	Sampling Days From Planting	Sampling Julian Date	Sampling Plant Part	Nutrient Element Analyzed (%)											
				N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	Si	Cl
T_2	50	149	PETIOLE	4.6	0.080	—	—	—	—	—	—	—	—	—	—
	65	164	PETIOLE	4.3	0.085	—	—	—	—	—	—	—	—	—	—
	80	179	PETIOLE	3.7	0.083										
	152	251	STRAW	0.7	0.080	1.30	0.18	0.18	0.09	0.0041	0.0065	0.0011	0.0032	8.52	0.030
	(Tillering)		PANICLE	2.3	0.070	1.40	0.42	0.50	0.07	0.0034	0.0050	0.0008	0.0011	1.43	0.025
			GRAIN	—	—	—	—	—	—	—	—	—	—	—	—
	172	271	STRAW	0.7	0.070	1.20	0.29	0.15	0.08	0.0032	0.0028	0.0012	0.0009	8.22	0.040
	(Flowering)		PANICLE	2.0	0.050	1.00	0.55	0.20	0.07	0.1050	0.0090	0.0014	0.0026	1.48	0.050
			GRAIN	1.6	0.060	0.90	0.13	0.13	0.11	0.0055	0.0021	0.0011	0.0030	2.00	0.030
	212	302	STRAW	0.6	0.110	1.20	0.31	0.18	0.09	0.0084	0.0020	0.0018	0.0024	8.00	0.035
	(Harvest)		PANICLE	2.0	0.040	0.40	0.62	0.25	0.08	0.0140	0.0070	0.0022	0.0012	1.60	0.055
			GRAIN	1.4	0.260	0.70	0.16	0.14	0.12	0.0096	0.0025	0.0030	0.0027	2.60	0.028
T_7	50	149	PETIOLE	4.3	0.085	—	—	—	—	—	—	—	—	—	—
	65	164	PETIOLE	4.4	0.090	—	—	—	—	—	—	—	—	—	—
	80	179	PETIOLE	3.8	0.090	—	—	—	—	—	—	—	—	—	—
	152	251	STRAW	0.8	0.250	1.60	0.80	0.08	0.70	0.0090	0.0071	0.0011	0.0060	8.04	0.04
	(Tillering)		PANICLE	1.8	0.150	0.80	1.20	0.11	0.05	0.0111	0.0070	0.0060	0.0022	1.20	0.05
			GRAIN	1.3	0.400	0.20	0.08	0.14	0.06	0.0050	0.0010	0.0020	0.0018	1.10	0.03
	172	271	STRAW	1.2	0.120	1.30	1.30	0.09	0.09	0.0110	0.0054	0.0007	0.0045	8.62	0.03
	(Flowering)		PANICLE	2.1	0.110	1.00	1.90	0.05	0.09	0.0100	0.0072	0.0080	0.0066	1.80	0.03
			GRAIN	1.4	0.900	0.18	0.08	0.16	0.11	0.0092	0.0016	0.0060	0.0040	1.60	0.02
	212	302	STRAW	1.1	0.130	0.70	0.48	0.23	0.11	0.0118	0.0053	0.0018	0.0160	10.12	0.03
			PANICLE	2.0	0.040	0.60	0.86	0.24	0.12	0.0210	0.0120	0.0024	0.0046	2.10	0.04
			GRAIN	1.5	0.290	0.60	0.26	0.21	0.16	0.1180	0.0052	0.0022	0.0026	3.20	0.02

Table 11. Plant nutrient analysis for cultivar IV 404 on the rice irrigation experiment planted on May 7, 1982 (Julian date 127) at Yuma, Arizona.

Irrigation Treatment 1/	Sampling Days From Planting	Sampling Julian Date	Sampling Plant Part	Nutrient Element Analyzed (%)											
				N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	Si	Cl
T_2	50	177	PETIOLE	4.2	0.120	—	—	—	—	—	—	—	—	—	—
	65	192	PETIOLE	3.7	0.140	—	—	—	—	—	—	—	—	—	—
	80	207	PETIOLE	3.4	0.155	—	—	—	—	—	—	—	—	—	—
	125	252	STRAW	1.1	0.080	1.40	0.16	0.18	0.086	0.0031	0.0048	0.0016	0.0018	7.68	0.025
	(Tillering)		PANICLE	2.5	0.690	1.50	0.36	0.12	0.084	0.0039	0.0048	0.0012	0.0021	1.20	0.030
			GRAIN	—	—	—	—	—	—	—	—	—	—	—	—
	145	272	STRAW	0.8	0.090	0.80	0.24	0.26	0.072	0.0024	0.0070	0.0016	0.0015	1.33	0.060
	(Flowering)		PANICLE	2.3	0.180	1.10	0.64	0.31	0.068	0.0150	0.0075	0.0016	0.0015	1.33	0.060
			GRAIN	1.5	0.260	0.30	0.16	0.18	0.100	0.0060	0.0060	0.0014	0.0024	1.24	0.030
	190	317	STRAW	0.7	0.070	0.80	0.30	0.28	0.080	0.0140	0.0030	0.0029	0.1027	9.12	0.630
	(Harvest)		PANICLE	2.0	0.050	0.50	0.60	0.34	0.120	0.0266	0.0070	0.0026	0.0130	1.52	0.025
			GRAIN	1.6	0.230	0.60	0.16	0.14	0.110	0.1180	0.0038	0.0038	0.0044	1.96	0.018
T_7	50	177	PETIOLE	3.6	0.105	—	—	—	—	—	—	—	—	—	—
	65	192	PETIOLE	3.6	0.090	—	—	—	—	—	—	—	—	—	—
	80	207	PETIOLE	3.2	0.065	—	—	—	—	—	—	—	—	—	—
	125	252	STRAW	0.9	1.800	1.30	1.30	0.07	0.090	0.0090	0.0076	0.0080	0.0036	8.86	0.040
	(Tillering)		PANICLE	2.4	0.140	1.20	1.70	0.10	0.120	0.0010	0.0064	0.0011	0.0018	1.20	0.050
			GRAIN	—	—	—	—	—	—	—	—	—	—	—	—
	145	272	STRAW	0.7	0.080	1.70	1.20	0.14	0.090	0.0250	0.0120	0.0160	0.0075	9.66	0.020
	(Flowering)		PANICLE	1.6	0.070	1.0–	2.00	0.18	0.150	0.0100	0.0010	0.0100	0.0028	1.80	0.030
			GRAIN	1.3	0.240	0.26	0.05	0.14	0.110	0.0820	0.0036	0.0028	0.0032	2.00	0.030
	190	317	STRAW	0.7	0.050	0.60	0.68	0.41	0.140	0.0180	0.0073	0.0030	0.0040	11.62	0.020
	(Harvest)		PANICLE	1.4	0.030	0.50	1.23	0.72	0.180	0.0240	0.0138	0.0018	0.0230	2.60	0.030
			GRAIN	1.5	0.310	0.70	0.30	0.23	0.160	0.0130	0.0038	0.0024	0.0048	4.60	0.020

Table 12. Summary of rice yields (kg/ha) from the observational nursery planted for two planting dates at Yuma, Arizona. 1982. 1/

Cultivar	Entry No.	Planting Dates April 9	May 7	Avg.
IR 528 Pk 13 E 1	(1)	4559	1686	3123
IR 1168-24-2-3-1	(2)	1009	650	830
KAR 27	(3)	5521	5375	5448
IR 28	(4)	4863	3786	4325
KAR 30	(5)	6175	5686	5931
TI	(6)	3440	2836	3138
PI 402 RP 414	(7)	7635	3223	5429
HZ ROS 637	(8)	5110	2180	3645
PI 403 RP 7923	(9)	9895	4624	7260
IR 944-93-2-1-2-2	(10)	4580	3690	4135
SHIOJI 74	(11)	2832	2160	2496
PI 432-566	(12)	7522	3285	5404
IR 2004-P7-1-1	(13)	6439	2744	4592
IR 422-2-58	(14)	10784	2295	6540
IV 56	(15)	7959	4670	6315
IV 404-6	(16)	8571	3896	6234
RAX 2402	(17)	6722	5606	6164
RAX 2404	(18)	6417	5151	5784
RAX 2406	(19)	7085	4194	5639
RAX 2408	(20)	6246	4732	5489
RAX 2404	(21)	3969	5957	4963
RAX 2412	(22)	9111	5197	7154
RAX 2414	(23)	8360	5692	7026
RAX 2416	(24)	5724	6164	5929
	(25)	-------	Not Planted	----------
PUSA 2-21	(26)	3591	3398	3495
PI 324-462	(27)	3661	3621	3641
CHEN CHUN YA	(28)	3616	3728	3672
IKAN POOCHEE	(29)	4000	3048	3524
NANG KENG 33	(30)	5867	3562	4715
IR 9209-89-11	(31)	4848	4115	4482
KAR 398	(32)	5000	4668	4834
IET 4094	(33)	3562	4174	3868
IR 5657-33-2-1-2	(34)	4009	3943	3976
SUWEON 258	(35)	3331	3606	3469
KIRAU	(36)	2563	1522	2043
IR 2006-P12-3-2	(37)	3314	1535	2425
IV 404	(38)	3919	2811	3365
IR 22	(39)	1914	3847	2881
IV 213	(40)	2216	3655	2936
IR 1108-3-5-3-2	(41)	3408	3387	3398
PI 432-560	(42)	1157	3071	2114
PI 324-462	(43)	3153	4789	3971
PI 433-220	(44)	3724	2098	2911
CHU CHINISA, CHINA	(45)	1644	2005	1825
IR 2153-26-3-5	(46)	4686	2902	3794
IR 1857-103-2-2	(47)	612	1835	1224
IV 330-1	(48)	2411	1905	2158

1/ Irrigation water was applied twice a week on all nursery plots.

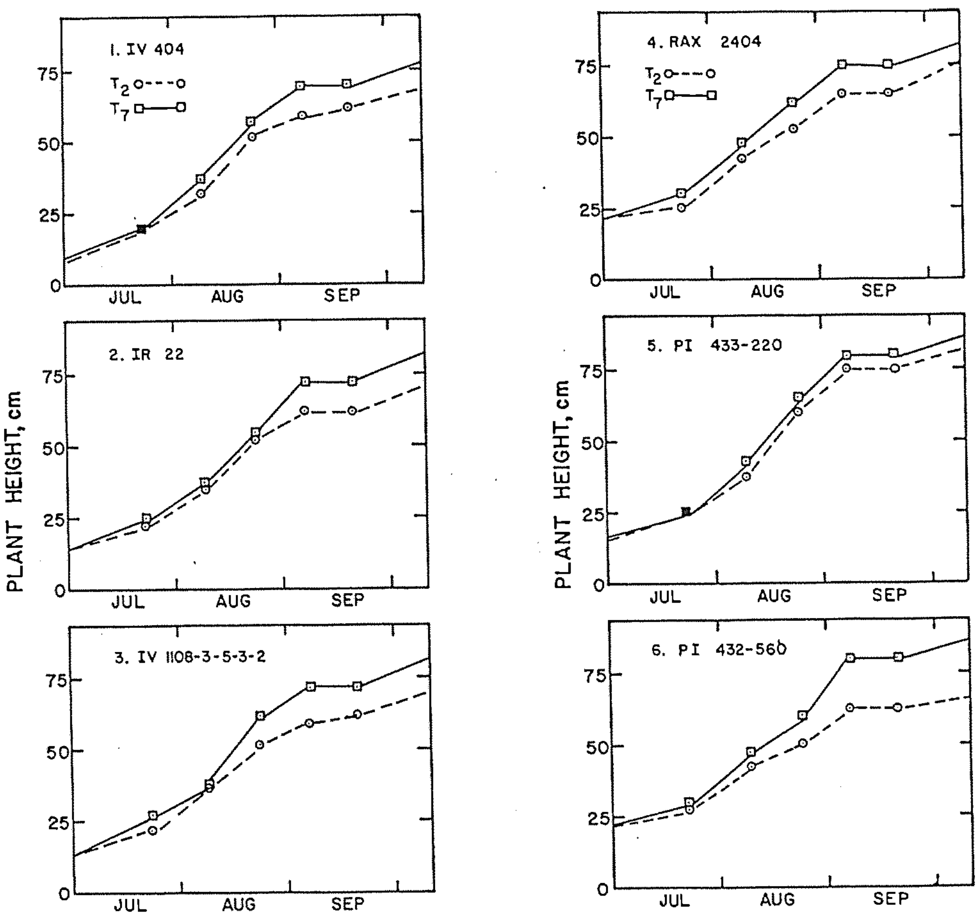

Figure 1. Effects of T_2 and T_7 irrigation treatments on plant growth for six rice cultivars planted at Yuma, Arizona, on April 9, 1982.

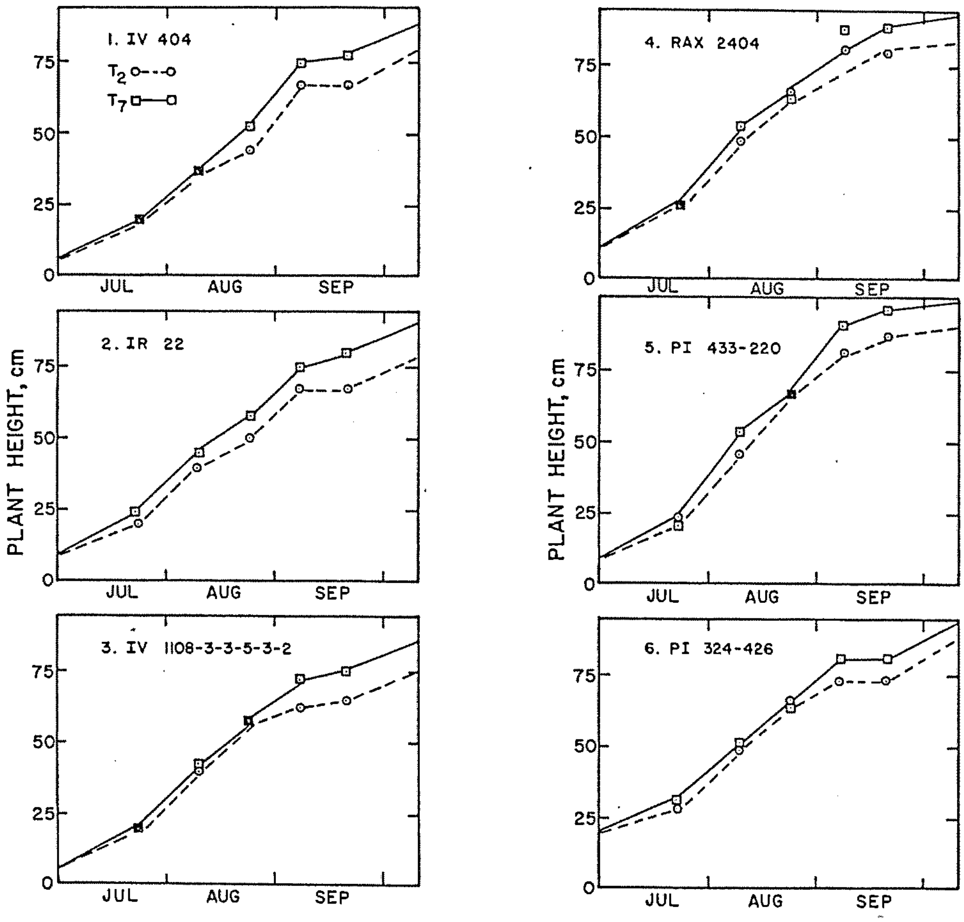

Figure 2. Effects of T_2 and T_7 irrigation treatments on plant growth for six rice cultivars planted at Yuma, Arizona, on May 7, 1982.

TITLE: IRRIGATION WATER, CULTURAL PRACTICES, AND ENERGY ASPECTS OF LETTUCE AND CABBAGE PRODUCTION IN ARID REGIONS

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

INTRODUCTION:

In the recent past, and certainly in the future, increased importance will come from the consumer for better quality and more nutritious vegetables at a reasonable cost. Arid regions of the southwestern United States have a unique and often envied position of being able to produce vegetables during the off-season when prices are generally high. However, growers face problems of increased labor and production costs. But of more importance is the need to conserve energy and natural resources essential in vegetable production, namely, water and fertilizer. The consumptive use of water for high-yielding lettuce and cabbage in the desert areas of central Arizona has been measured at about 22 cm (8.5 inches) and 44 cm (17.2 inches), respectively. In some instances as much as four times these amounts of water are applied to a single vegetable crop.

Although considerable research has been done with sprinklers, little effort has been made to use efficient level-basin systems in conjunction with flat or nearly-flat plantings for continuous vegetable production. Sprinkler irrigation systems are being used to reduce water requirements for germination, but high rental or purchasing and operating costs are making this approach less appealing. Level-basin irrigation is one of the few existing alternatives for improving irrigation efficiency on a large scale without incurring excessive costs. Flat plantings have the additional advantages of possibly increasing yield with higher plant populations, reducing cultivations, improving salinity management, adapting to mechanical harvest machinery, and shortening the time period between harvest and planting of the next crop.

The objectives of this experiment are: (1) to develop energy conserving, level basin irrigation systems that most nearly meet the determined consumptive-use requirements without adversely effecting lettuce and cabbage production; (2) to determine if flat plantings and increased plant populations can be used to increase overall lettuce and/or cabbage production; and (3) to determine the interrelationships that these changes may create relative to planting, fertilization, weed control, harvesting, and intensified vegetable production.

Spring Lettuce - 1981

Field Procedures

The 1981 spring cropping season consisted of three planting methods: (1) conventional vegetable bed with a 46 cm (18 inches) top width and two rows spaced 35 cm (14 inches) apart along with plants spaced 25 cm (10 inches) within each row. The beds were 100 cm (40 inches) apart, center to center; (2) corrugated planting with ridges 50 cm (20 inches) apart and a

25 cm (10 inches) plant row spacing. The size of corrugations were approximately 6 cm (2.4 inches) high and 20 cm (7.9 inches) wide; and (3) flat planting with rows 38 cm (15 inches) apart and a 25 cm (10 inches) plant row spacing. The plant populations were about 77,000 plants/hectare on the standard beds and corrugations, and 97,000 on the flat. In addition, three irrigation treatments were based on soil water depletion levels of 40, 55, and 70% in the top 90 cm (3 ft) of soil. The nine planting and irrigation treatment combinations were replicated four times in a randomized-block design for a total of 36 plots. Each individual plot was 6.7 m wide x 18.3 m long (22 x 60 ft). The field layout is shown in Fig. 1.

Vanguard lettuce seed was planted and irrigated up on November 26, 1980. The standard beds received 9.4 cm (3.7 inches) and 7.9 cm (3.1 inches); the corrugated plantings received 10.1 cm (4 inches) and 7.9 cm (3.1 inches); and the flat plantings received 13 cm (5.1 inches) and 11.2 cm (4.4 inches), on November 26 and December 5, respectively. Plots were thinned from December 15-19, and all plots received 8.5 cm (3.3 inches) of water on December 23. Subsequent irrigations for the wet treatment were 7.4 cm (2.9 inches), January 21; 9.1 cm (3.6 inches), February 20; 8.6 cm (3.4 inches), March 11; and 8.4 cm (3.3 inches), March 19. The medium treatment received 9.9 cm (3.9 inches), February 4; 9.7 cm (3.8 inches), February 27; and 8.4 cm (3.3 inches), March 19. Lastly, the dry treatment included 9.1 cm (3.6 inches), February 20, and 8.6 cm (3.4 inches), March 11. Total seasonal water applied for the three irrigation treatments are shown in Table 1. All water measurements were made with a 10-cm (4-inch) propeller-type water meter.

Every plot received fertilizer applications at 168 kg/ha (150 lb/acre) of ammonium phosphate (16-20-0) broadcasted before planting, and two subsequent applications at 112 kg/ha (100 lb/acre) each using urea (46% N) in the first two irrigations following thinning. The total N fertilizer applied was 130 kg/ha (116 lb/acre), and P fertilizer was 34 kg/ha (30 lb/acre). Insects were controlled with timely applications of meth -myl (5-Methyl-methylcarbamoyl-N-thioacetimidate) and phosdrin (2-Methoxy-bonyl-1-methylvindyldimethyl-phosphate) insecticides.

Consumptive water use was calculated from changes in soil water content at two sites with two locations per site for every treatment combination. Soil moisture samples were taken to a depth of 90 cm (3 ft). Lettuce was harvested on March 30 and April 6, and lettuce heads were graded according to U. S. Standards, either 1-1/2, 2, or 2-1/2. A standard carton holds 18 (1-1/2's), 24 (2's), or 30 (2-1/2's). Yields were taken from 15.5 m^2 (167 ft^2) and expressed as cartons per hectare.

RESULTS AND DISCUSSION:

The measured seasonal consumptive use of water for lettuce was 23 cm (1 .6 inches), 28 cm (11.1 inches), and 26 cm (10.1 inches) for the wet, medium, and dry treatments, respectively. Seasonal variations are shown in Figs. 2, 3, and 4. Soil moisture tensions did not reach suggested values at time of irrigation, although differences did occur. Soil moisture depletions prior to irrigation were 28, 46, and 53% at a soil depth of 90 cm (3 ft) for the wet, medium, and dry treatments, respectively (Table 1). Estimated irrigation application efficiency (consumptive use divided by water applied, expressed as a percentage) averaged 53% with little difference in efficiency between the three planting methods.

Yields for spring lettuce are summarized in Table 2. The yields showed very little difference between irrigation treatments. The total cartons per hectare were also nearly the same for the conventional bed and corrugated planting methods which had about the same plant population. However, the flat planting produced an increase of 26% over the other two planting methods. This relates to the 25% increase in plant population on the flat plantings.

Fall Lettuce and Cabbage - 1981

FIELD PROCEDURES:

The fall 1981 experiment was identical to the spring 1981 plan, except that each plot was planted one-half to lettuce and one-half to cabbage rather than all lettuce. The nine planting and irrigation treatment combinations remained in a randomized block design with four replications. The scheduling of irrigations was based on soil water depletion levels for the lettuce only. Water measurement, thinning, soil moisture sampling, and harvesting procedures were identical to those used for the spring crop.

Empire lettuce and Headstart cabbage seed was planted on September 10. On September 11, 9.6 cm (3.8 inches) of irrigation water was applied to all plots. An additional 10.6 cm (4.2 inches) and 6.4 cm (2.5 inches) were given on September 13 and 23, respectively, for germination and stand establishment. Plots were thinned from October 5-7, followed by an application of 8 cm (2.8 inches) of water on October 8. Thereafter, the wet irrigation treatment received 7 cm (2.7 inches), October 16; 7.1 cm (2.8 inches), November 12; and 6.9 cm (2.7 inches), December 10. The medium treatment received 7.2 cm (2.8 inches), October 30, and 6.1 cm (2.4 inches), November 15. The dry treatment was given 7.1 cm (2.8 inches), November 12. Total seasonal water applications for each irrigation regime are given in Tables 3 and 4.

Fertilizer applications were identical to those on the spring lettuce. Aphids and cabbage loopers were controlled with periodic applications of methomyl and phosdrin insecticides. In addition, numerous applications of malathion (0,0-Dimethyl S-1,2-dicharbethoxyethyl, phosphorodithioate) were used to reduce damaged caused by a widespread whitefly infestation.

RESULTS AND DISCUSSION:

The measured seasonal consumptive use of water for fall lettuce was 22 cm (8.6 inches), 18 cm (6.9 inches), and 14 cm (5.4 inches) for the wet, medium and dry irrigation treatments, respectively (Figs. 5-7). These consumptive use values for the fall lettuce were based on actual soil water depletion levels of 40, 60 and 72%, at a soil depth of 90 cm (3 ft) on the wet, medium, and dry treatments, respectively (Table 3). The consumptive water use for cabbage was 25 cm (10.0 inches), 23 cm (9.1 inches), and 18 cm (7.1 inches) for the three irrigation treatments (Fig. 8-10). As with the lettuce, the values were based on actual soil water depletion levels of 52, 79, and 90% at a soil depth of 90 cm (3 ft) on the wet, medium, and dry treatments (Table 4).

Irrigation application efficiencies were about 36% for fall lettuce (Table 3) and 46% for fall cabbage (Table 4). This is some improvement over the 25-30% generally achieved by commerical growers. Considerable irrigation water is wasted in the germination process when temperatures are hot in an attempt to keep seeds moist and soil temperatures cool. Temperatures should be below 37.8 C (79 F) or less for at least four hours to ensure an adequate germination percentage. To accomplish the necessary cooling extra irrigation water may be needed. There was little difference in the amounts of water applied for stand establishment or the seasonal irrigation efficiences for the three planting methods.

Yields for fall lettuce are summarized in Table 5. As with spring lettuce, there was little difference between irrigation treatments. The flat planting, however, showed a 25% increase in yield compared with the bed and corrugation methods. This corresponds directly to the 25% increase in plant population on the flat planting. Differences between planting methods were significant at the 1% level. Overall, fall lettuce production was lower than expected because of the whitefly problem although the comparisons between treatments should not have been affected.

Fall cabbage yields are reported as number of 227 kg (50 lb) cartons/hectare in Table 6. There was no significant difference in the fall cabbage yield between the wet and medium irrigation treatments, but they yielded 10% more than the dry treatment. The flat planting method had 6% less cartons, even though the plant population was higher than under the bed and corrugation methods. Individuals heads grown under the flat planted conditions were smaller, resulting in the lower total weight. This indicates that there may not have been enough water to support the increased number of plants on the flat planting. The conventional beds yielded 16% more than the other two methods. Perhaps, more available water was stored in the beds which produced heads that weighed more and increased yields.

Spring Lettuce and Cabbage - 1982

FIELD PROCEDURES:

The lettuce and cabbage studies were moved to a larger field in 1982. Because each plot was now 10.1 m wide x 18.3 m long (33 x 60 ft), a third crop, Chinese cabbage, was planted in addition lettuce and cabbage. Fig. 11 shows a diagram of the nine planting and irrigation treatment combinations for the three crops. All physical and mechanical procedures were carried out as described in the previous two experiments.

Ammonium phosphate at 168 kg/ha (150 lb/acre) was broadcasted over the experiment area prior to planting. Vanguard lettuce, Headstart cabbage, and Bok Choy Chinese cabbage were planted on November 20, 1981. All plots received 8.1 cm (3.2 inches) of irrigation water for germination purposes and an excellent stand was obtained on all planting methods. An additional 5.6 cm (2.2 inches) irrigation was given on November 25. Temperatures were warmer than normal in December, and no rainfall occurred. Because of the warm temperatures, weeds became a problem and the plots were cultivated in late December. After the cultivation, temperatures continued warm, and noticeable soil drying occurred that necessitated another irrigation of 6.5 cm (2.5 inches) that resulted was to maintain stands.

Plots were thinned from January 25-27. Ninety-five kg/ha (85 lb/acre) of urea followed by an 8.4 cm (3.3 inches) application of water on January 28. Thereafter, the wet treatment received 7.1 cm (2.8 inches), February 23; 8.4 cm (3.3 inches), March 24; and 6.9 cm (2.7 inches), April 5. The medium treatment received 7.4 cm (2.9 inches), March 2, and 6.9 cm (2.7 inches), April 5. An additional 95 kg/ha (85 lb/acre) of urea was applied to all plots on March 18. A total of 11.3 cm (4.45 inches) of rain fell during the growing period from November 28 to May 1. A summary of the seasonal water applied for the different irrigation treatments is shown in Table 7.

RESULTS AND DISCUSSION:

The measured seasonal consumptive use of water for the 1982 spring lettuce was 33 cm (12.9 inches), 33 cm (12.8 inches), and 25 cm (10.0 inches) for the wet, medium, and dry irrigation treatments, respectively (Figs. 12-14). Only the information on the medium treatment for cabbage indicated that 35 cm (13.8 inches) of water was consumptively used (Fig. 15). The consumptive use values on the spring lettuce were based on actual soil water depletion levels of 43, 50, and 63% for the wet, medium, and dry irrigation treatments, respectively. The irrigation on the medium irrigation treatment with spring cabbage averaged 50% soil water depletion in a 90 cm (3 ft) soil depth. Irrigation efficiencies averaged 55% for spring lettuce and 65% for spring cabbage.

Due to higher than normal temperatures during the growing season, the Chinese cabbage bolted and was disked down before being harvested. The flat planting for the spring lettuce produced 25% more cartons than the other two planting methods, which corresponded to the 25% increase in plant population for the flat planting. The wet irrigation treatment yielded 8% more cartons than the medium treatment, and 22% more than the dry treatment (Table 8). The noted differences were significant at the 1% level.

Spring cabbage planted on standard beds outyielded the other two methods by over 30%. The wet irrigation treatment produced 26% more cartons than the medium treatment, and 42% more than the dry one. These data were again significant at the 1% level (Table 9).

SUMMARY AND CONCLUSIONS:

Lettuce was grown in the spring of 1981 and 1982 and fall of 1981 under wet, medium, and dry irrigation treatments and three planting methods including standard beds, raised corrugations, and flat plantings. For the three seasons, the flat-planted lettuce had the 25% greater plant population and produced a 25% greater yield over the corrugated and conventional bed plantings. Insignificant differences in lettuce yields resulted from the various irrigation levels; however, the data indicated that an irrigation should be given when about 50% soil water depletion is reached in the top 90 cm of soil depth. The seasonal consumptive use of water was approximately 28 and 33 cm for the spring lettuce in 1981 and 1982, respectively, and 18 cm for the fall lettuce in 1981. With lettuce, the potential for the flat culture with higher plant populations include increased yield, higher water-use efficiency (yield per amount of consumptive water use), improved salinity management, reduced tillage, and adaptability to newer mechanical or conventional harvesting techniques.

Cabbage was also grown in the fall of 1981 and spring of 1982 using the same three irrigation and three planting treatments as for the lettuce. Cabbage yields were affected by irrigation amounts and planting methods. The highest yields being obtained from the wet irrigation treatment grown on the standard beds. The conventional beds showed more than a 20% yield increase compared with the flat and corrugated-planted cabbage. The lower yields on the high-population, flat planting resulted from smaller heads possibly caused by overcrowding and indequate irrigation. The consumptive water use was about 25 and 35 cm for the wet irrigation treatment on the fall and spring cabbage. Earlier research data indicate that maximum cabbage production has a consumptive water use requirement of about 44 cm of water. Therefore, the cabbage crops in these experiments may not have received enough irrigation water to realize the full yield potential under the various planting methods. Further studies are needed to determine how high-population cabbage could be used to control head size under limited irrigations.

PERSONNEL: D. A. Bucks, O. F. French (U. S. Water Conservation Laboratory); W. D. Pew, W. L. Alexander (Universtiry of Arizona, Mesa Experiment Farm).

Table 1. Water applications, measured consumptive use, and estimated irrigation application efficiencies for three irrigation treatments and planting methods on spring lettuce, 1981.

Irrigation Treatment	Planting Method	Total Number of Irrigations	Average Soil Moisture Depletion Prior to Irrigation*	Total Seasonal Water Applied	Measured Seasonal Consumptive Use	Estimated Irrigation Application Efficiency**
	Bed	7	25.0	23.3	12.2	52.4
Wet	Corrugation	7	32.1	23.6	13.3	56.4
	Flat	7	27.4	26.0	12.5	48.1
	Bed	6	43.2	21.2	10.6	50.0
Medium	Corrugation	6	49.0	21.5	10.8	50.2
	Flat	6	44.3	23.9	11.9	49.8
	Bed	5	53.7	17.1	9.9	57.9
Dry	Corrugation	5	53.0	17.4	10.2	58.6
	Flat	5	50.3	19.8	10.4	52.5

* Based on irrigations after establishment and a soil depth of 90 cm (3 ft).

** Measured seasonal consumptive use divided by total seasonal water supplied, expressed as a percentage.

Table 2. Summary of spring lettuce yields (mean of four replications), 1981.

Irrigation Treatment	Planting Method	Plant Population	Cartons Per Hectare
Wet	Bed	77,000/ha	2385b*
Wet	Corrugation	77,000/ha	2310b
Wet	Flat	97,000/ha	2869a
Medium	Bed	77,000/ha	2405b
Medium	Corrugation	77,000/ha	1991b
Medium	Flat	97,000/ha	2857a
Dry	Bed	77,000/ha	2336b
Dry	Corrugation	77,000/ha	2303b
Dry	Flat	97,000/ha	2916a

*Means followed by the same letter belong to the same population at the 5% level of significance (Duncan's Multiple Range test, $s_{\bar{x}}$ = 140 cartons/hectare).

Table 3. Water applications, measured consumptive use, and estimated irrigation application efficiences for three irrigation treatments and planting methods on fall lettuce, 1981.

Irrigation Treatment	Planting Method	Total Number of Irrigations	Average Soil Moisture Depletion Prior to Irrigation*	Total Seasonal Water Applied	Measured Seasonal Consumptive Use	Estimated Irrigation Application Efficiency**
	Bed	7	41.0	22.98	9.4	40.9
Wet	Corrugation	7	40.8	22.98	8.2	35.7
	Flat	7	39.7	22.98	8.3	36.1
	Bed	6	55.4	19.93	6.5	32.6
Medium	Corrugation	6	60.0	19.93	7.2	36.1
	Flat	6	63.6	19.93	7.0	35.1
	Bed	5	73.3	17.50	5.8	33.1
Dry	Corrugation	5	73.8	17.50	5.4	30.9
	Flat	5	70.5	17.50	5.0	28.6

* Based on irrigations after establishment and a soil depth of 90 cm (3 ft).
** Measured seasonal consumptive use divided by total seasonal water supplied, expressed as a percentage.

Table 4. Water applications, measured consumptive use, and estimated irrigation application efficiencies for three irrigation treatments and planting methods on fall cabbage, 1981.

Irrigation Treatment	Planting Method	Total Number of Irrigations	Average Soil Moisture Depletion Prior to Irrigation*	Total Seasonal Water Applied	Measured Seasonal Consumptive Use	Estimated Irrigation Application Efficiency**
	Bed	7	54.8	22.98	10.2	44.4
Wet	Corrugation	7	56.6	22.98	10.7	46.6
	Flat	7	47.2	22.98	9.2	40.0
	Bed	6	76.8	19.93	9.5	47.7
Medium	Corrugation	6	77.5	19.93	9.3	46.7
	Flat	6	83.8	19.93	8.7	43.7
	Bed	5	91.0	17.50	7.1	40.6
Dry	Corrugation	5	81.9	17.50	6.6	37.7
	Flat	5	98.1	17.50	7.4	42.3

* Based on irrigations after establishment and a soil depth of 90 cm (3 ft).
** Measured seasonal consumptive use divided by total seasonal water supplied, expressed as a percentage.

Table 5. Summary of fall lettuce yields (mean of 4 replications), 1981.

Irrigation Treatment	Planting Method	Plant Population	Cartons Per Hectare
Wet	Bed	77,000/ha	2063b*
Wet	Corrugation	77,000/ha	2086b
Wet	Flat	97,000/ha	2378a
Medium	Bed	77,000/ha	1883b
Medium	Corrugation	77,000/ha	2011b
Medium	Flat	97,000/ha	2405a
Dry	Bed	77,000/ha	1871b
Dry	Corrugation	77,000/ha	2087b
Dry	Flat	97,000/ha	2360a

*Means followed by the sam letter belong to the same population at the 5% level of significance (Duncan's Multiple Range test, $s\bar{x}$ = 70.3 cartons/hectare).

Table 6. Summary of fall cabbage yields (mean of 4 replications), 1981.

Irrigation Treatment	Planting Method	Plant Population	Cartons* Per Hectare
Wet	Bed	77,000/ha	2966ab**
Wet	Corrugation	77,000/ha	2644bc
Wet	Flat	97,000/ha	2789abc
Medium	Bed	77,000/ha	3215a
Medium	Corrugation	77,000/ha	2514bc
Medium	Flat	97,000/ha	2676bc
Dry	Bed	77,000/ha	2824abc
Dry	Corrugation	77,000/ha	2476bc
Dry	Flat	97,000/ha	2353c

*One carton = 22.7 kg (50 lb)
**Means followed by the same letter belong to the same population at the 5% level of significance (Duncan's Multiple Range test, $s\bar{x}$ = 157 cartons/hectare).

Table 7. Water applications, measured consumptive use,, and estimated irrigation application efficiencies for three irrigation treatments and planting methods on spring lettuce and cabbage, 1982.

Irrigation Treatment	Planting Method	Total Number of Irrigations	Average Soil Moisture Depletion Prior to Irrigation*	Total Seasonal Water Applied	Measured Seasonal Consumptive Use	Estimated Irrigation Application Efficiency**
	Bed	7	39.5	24.48	12.1	49.4
Wet	Corrugation	7	43.8	24.48	12.1	49.4
Lettuce	Flat	7	44.4	24.48	14.4	58.8
	Bed	6	50.0	21.31	12.4	58.2
Medium	Corrugation	6	50.8	21.31	12.3	57.7
Lettuce	Flat	6	50.2	21.31	13.6	63.8
	Bed	5	48.5	18.43	10.0	54.3
Dry	Corrugation	5	73.0	18.43	10.1	54.8
Lettuce	Flat	5	66.4	18.43	10.0	54.3
	Bed	6	55.9	21.31	13.7	64.3
Medium***	Corrugation	6	57.5	21.31	14.4	67.6
Cabbage	Flat	6	53.3	21.31	13.2	61.9

* Based on irrigations after establishment and a soil depth of 90 cm (3 ft).
** Measured seasonal consumptive use divided by total seasonal water supplied, expressed as a percentage.
*** Only the medium treatment on cabbage was measured for consumptive use.

Table 8. Summary of spring lettuce yields (means of 4 replications), 1982.

Irrigation Treatment	Planting Method	Plant Population	Cartons Per Hectare
Wet	Bed	77,000/ha	2937ab*
Wet	Corrugation	77,000/ha	2430cd
Wet	Flat	97,000/ha	3359a
Medium	Bed	77,000/ha	2824bc
Medium	Corrugation	77,000/ha	2280d
Medium	Flat	97,000/ha	3010ab
Dry	Bed	77,000/ha	2460cd
Dry	Corrugation	77,000/ha	1801c
Dry	Flat	97,000/ha	2865bc

*Means followed by the sam letter belong to the same population at the 5% level of significance (Duncan's Multiple Range test, $s_{\bar{x}}$ = 155 cartons/hectare).

Table 9. Summary of spring cabbage yields (mean of 4 replications), 1982.

Irrigation Treatment	Planting Method	Plant Population	Cartons* Per Hectare
Wet	Bed	77,000/ha	2472a**
Wet	Corrugation	77,000/ha	1950ab
Wet	Flat	97,000/ha	1770bc
Medium	Bed	77,000/ha	2385a
Medium	Corrugation	77,000/ha	1349c
Medium	Flat	97,000/ha	1169c
Dry	Bed	77,000/ha	1704bc
Dry	Corrugation	77,000/ha	1291c
Dry	Flat	97,000/ha	1346c

*One carton = 22.7 kg (50 lb)

**Means followed by the same letter belong to the same population at the 5% level of significance (Duncan's Multiple Range test, $s_{\bar{x}}$ = 157 cartons/hectare).

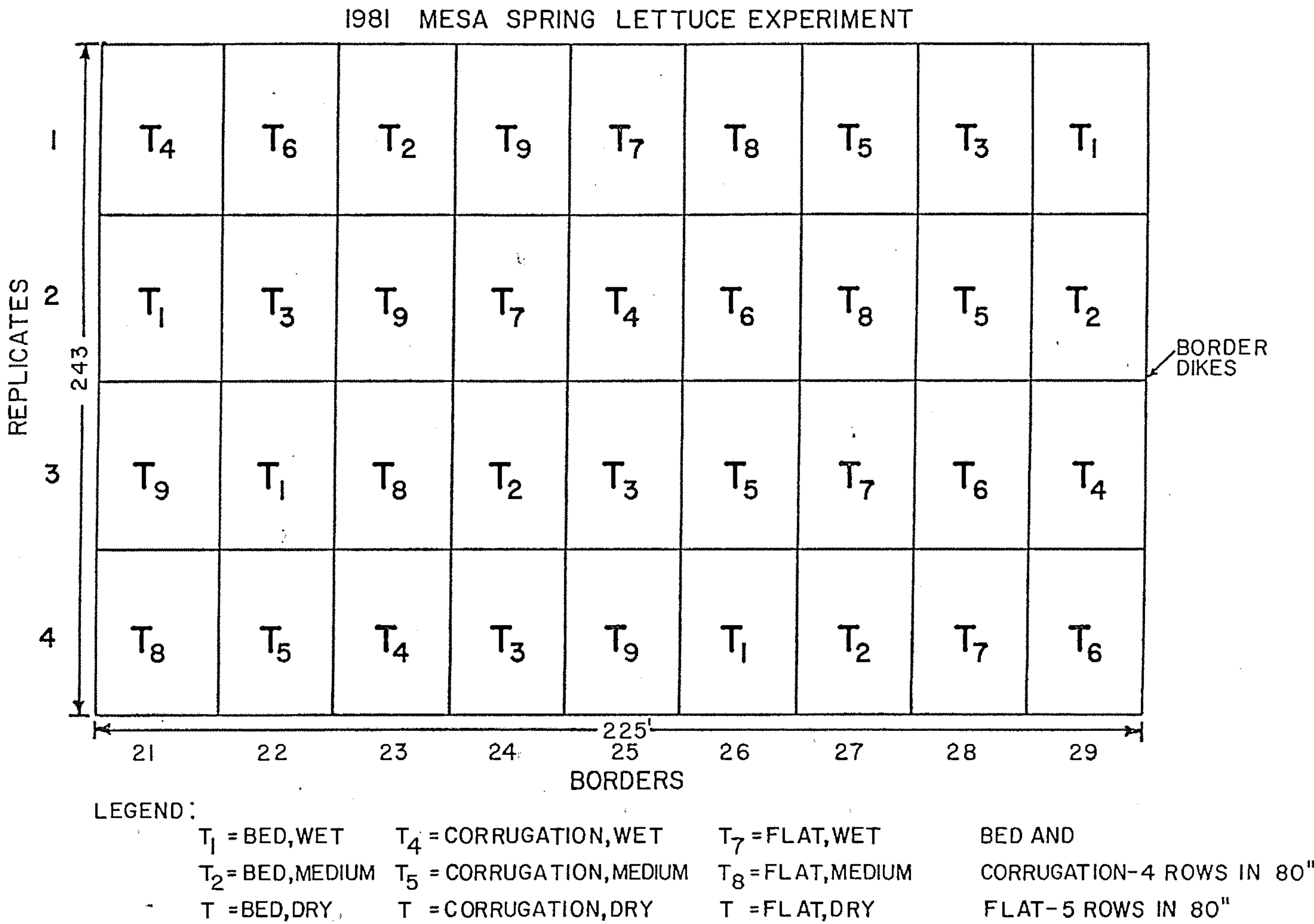

Figure 1. Plot diagram, planting method, and irrigation treatments for spring lettuce at Mesa, Arizona, 1981.

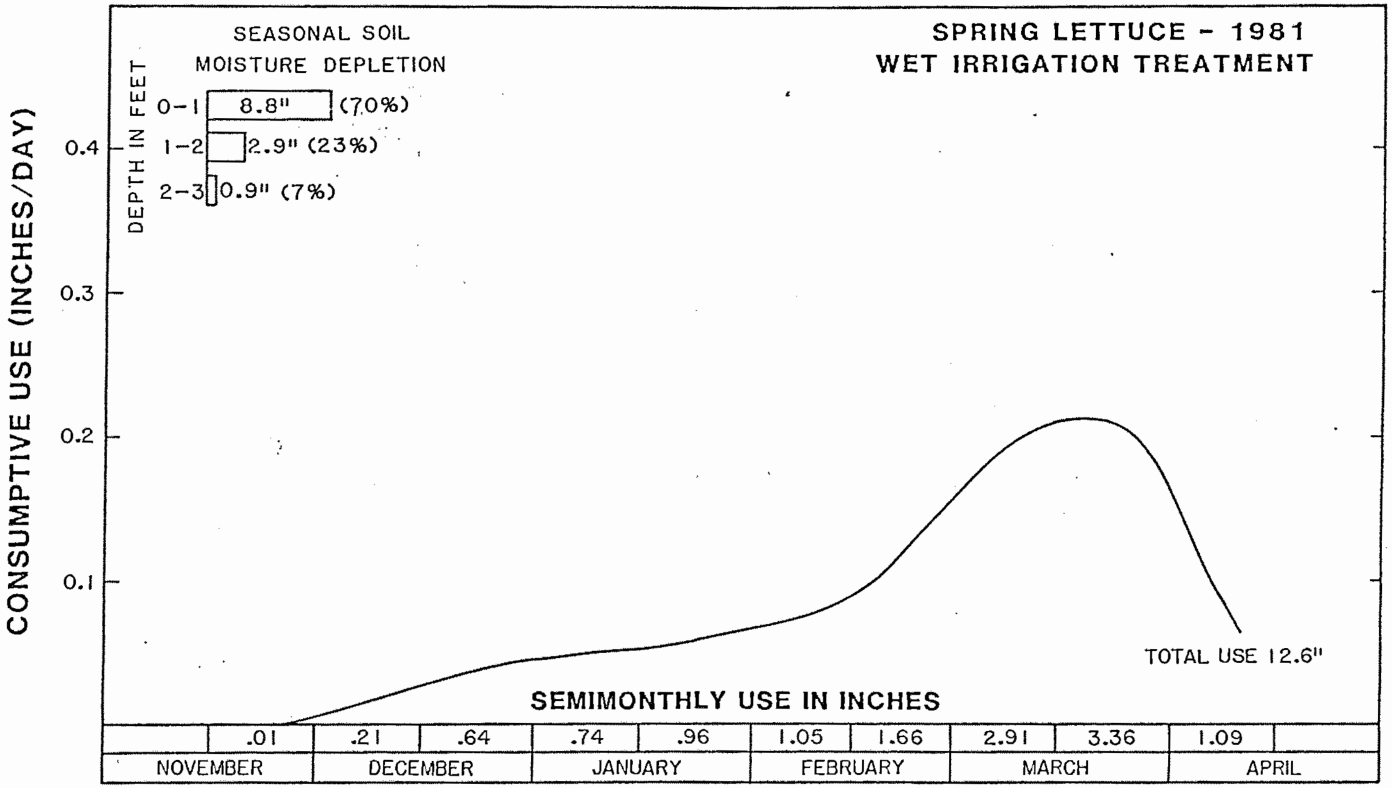

Figure 2. Mean consumptive use curve for a wet irrigation treatment on spring lettuce at Mesa, Arizona, 1981.

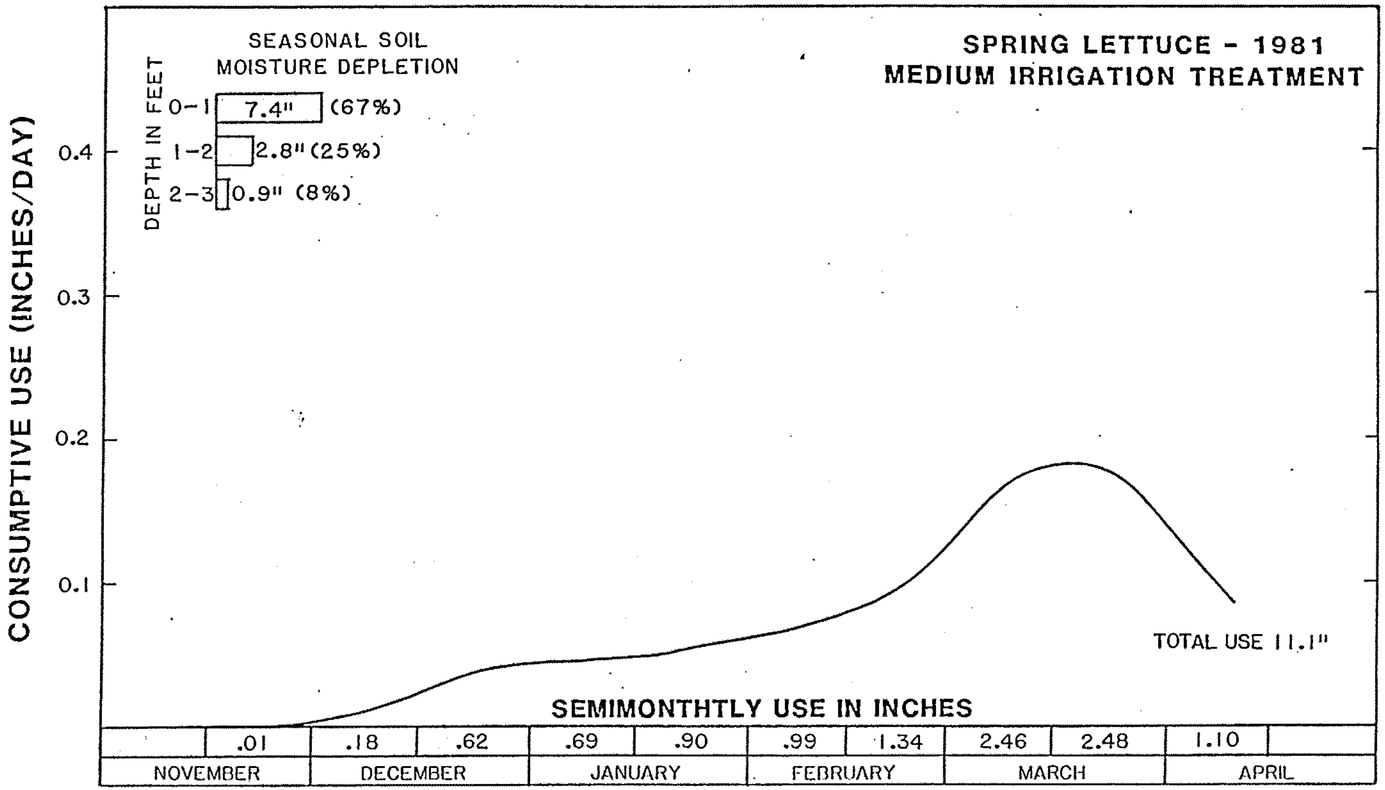

Figure 3. Mean consumptive use curve for a medium irrigation treatment on spring lettuce at Mesa, Arizona, 1981.

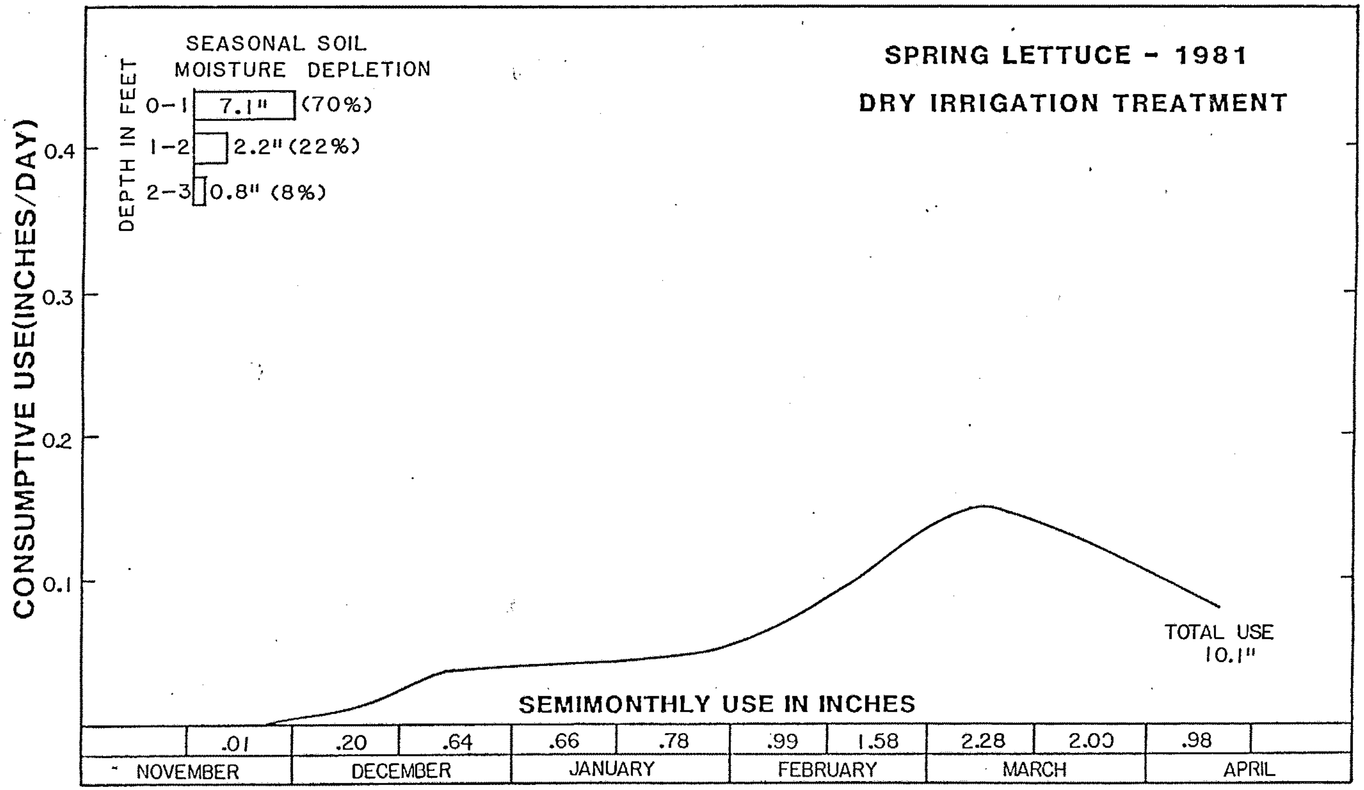

Figure 4. Mean consumptive use curve for a dry irrigation treatment on spring lettuce at Mesa, Arizona, 1981.

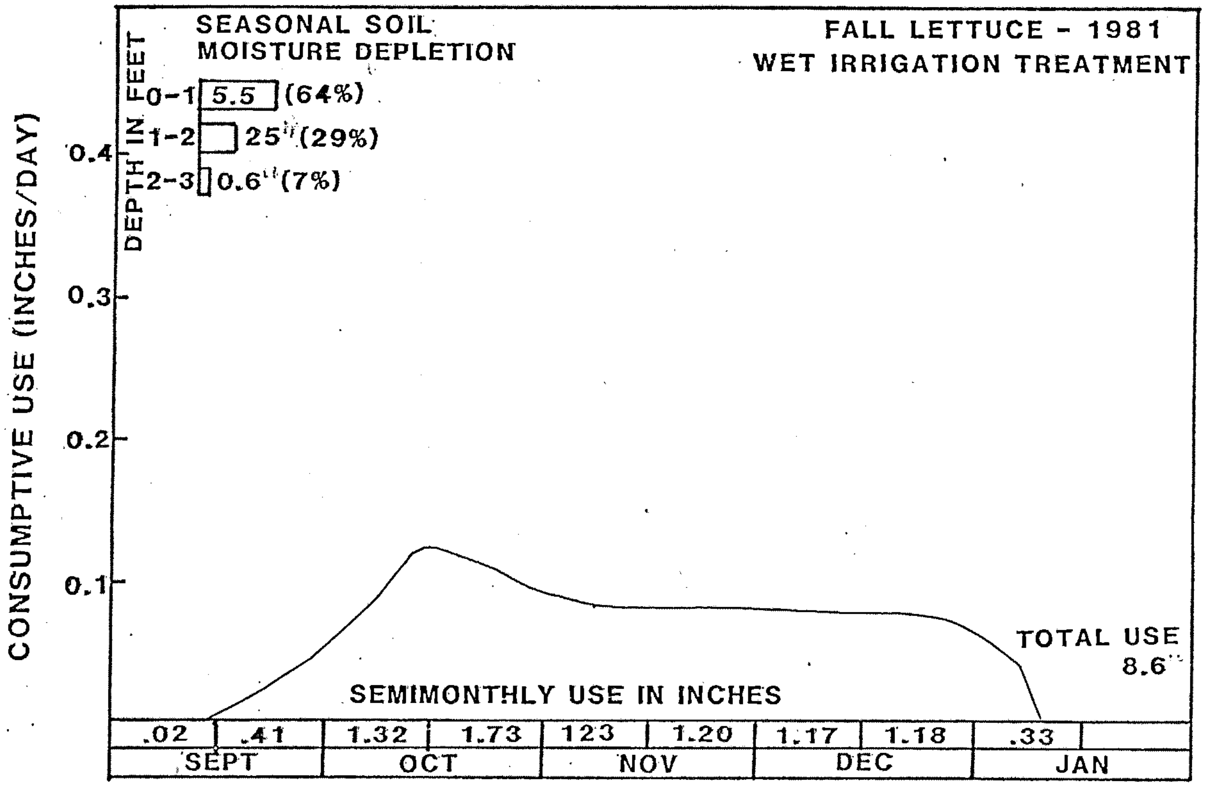

Figure 5. Mean consumptive use curve for a wet irrigation treatment on fall lettuce at Mesa, Arizona, 1981.

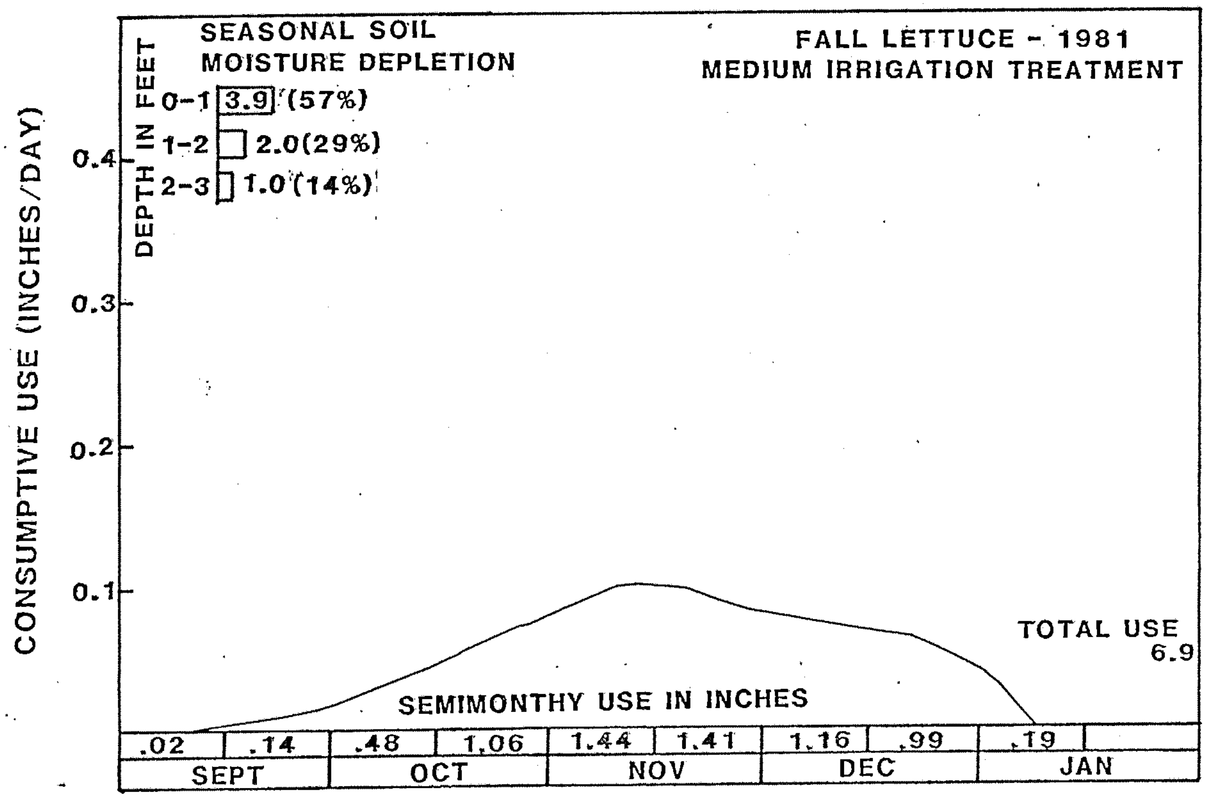

Figure 6. Mean consumptive use curve for a medium irrigation treatment on fall lettuce at Mesa, Arizona, 1981.

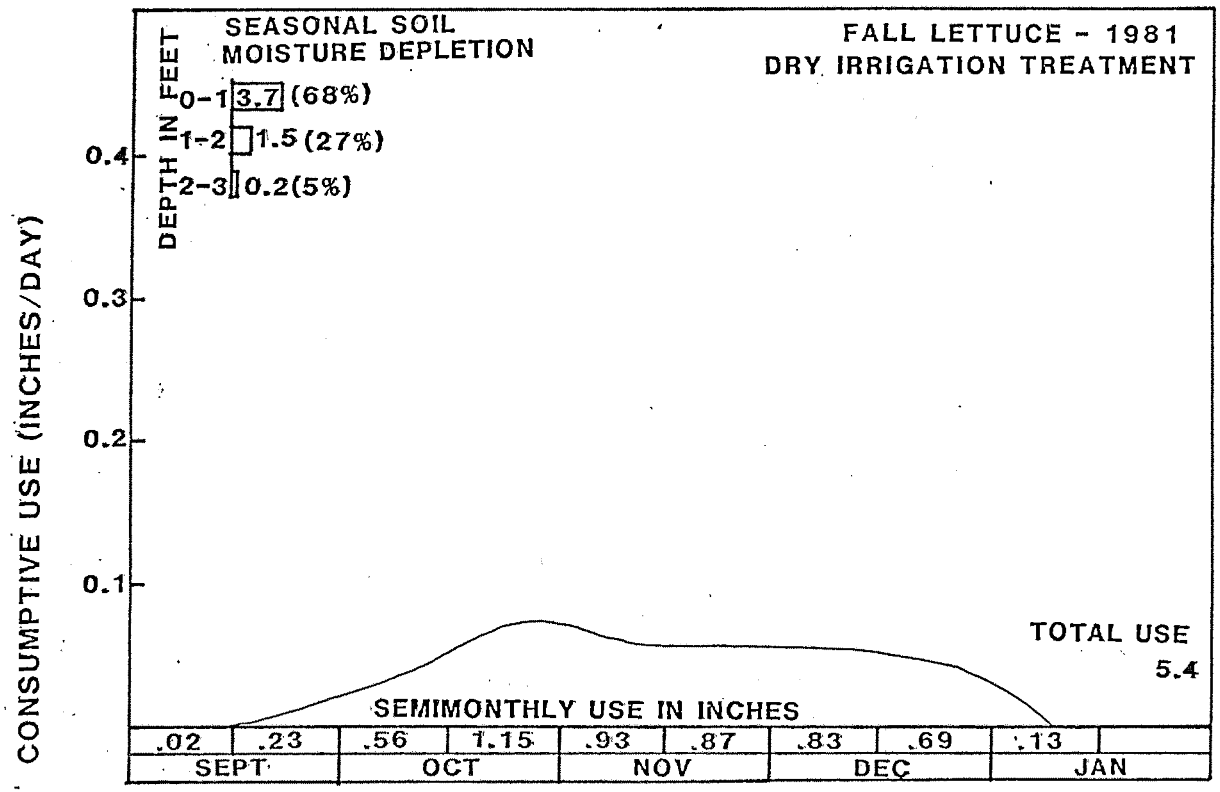

Figure 7. Mean consumptive use curve for a dry irrigation treatment on fall lettuce at Mesa, Arizona, 1981.

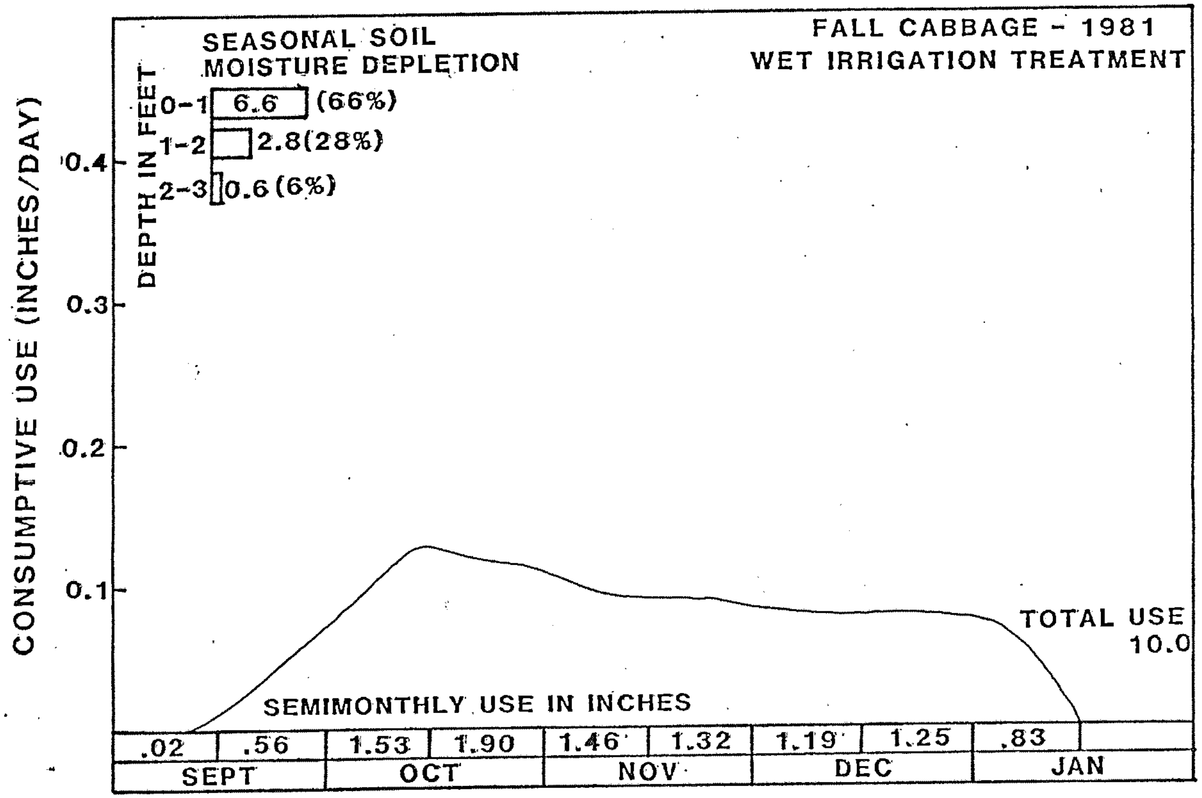

Figure 8. Mean consumptive use curve for a wet irrigation treatment on fall cabbage at Mesa, Arizona, 1981.

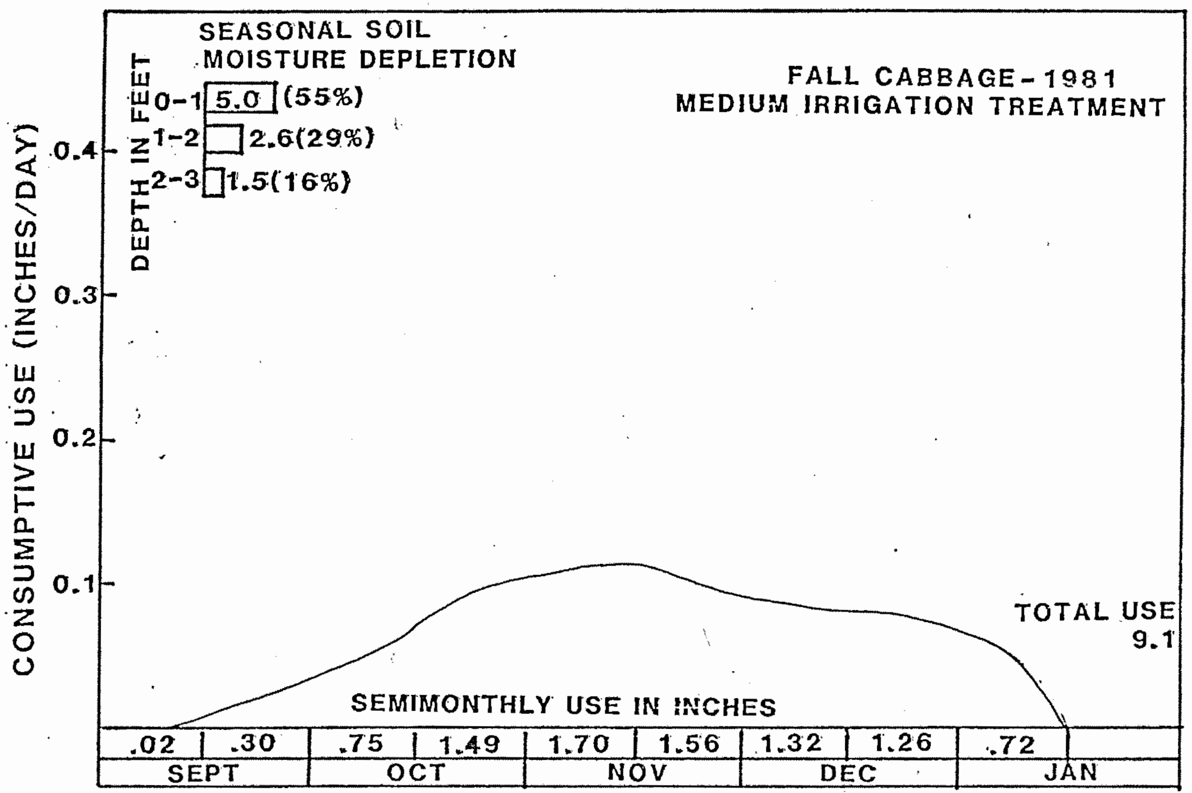

Figure 9. Mean consumptive use curve for a medium irrigation treatment on fall cabbage at Mesa, Arizona, 1981.

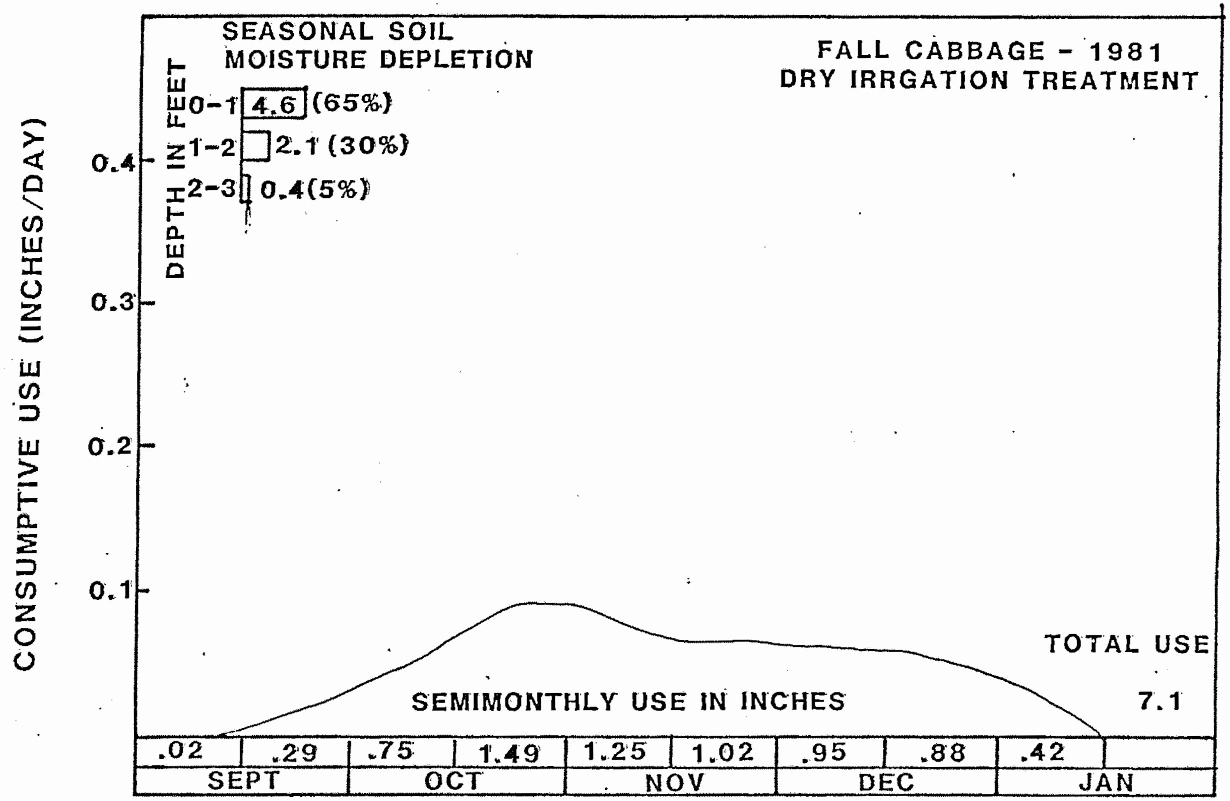

Figure 10. Mean consumptive use curve for a dry irrigation treatment on fall cabbage at Mesa, Arizona, 1981.

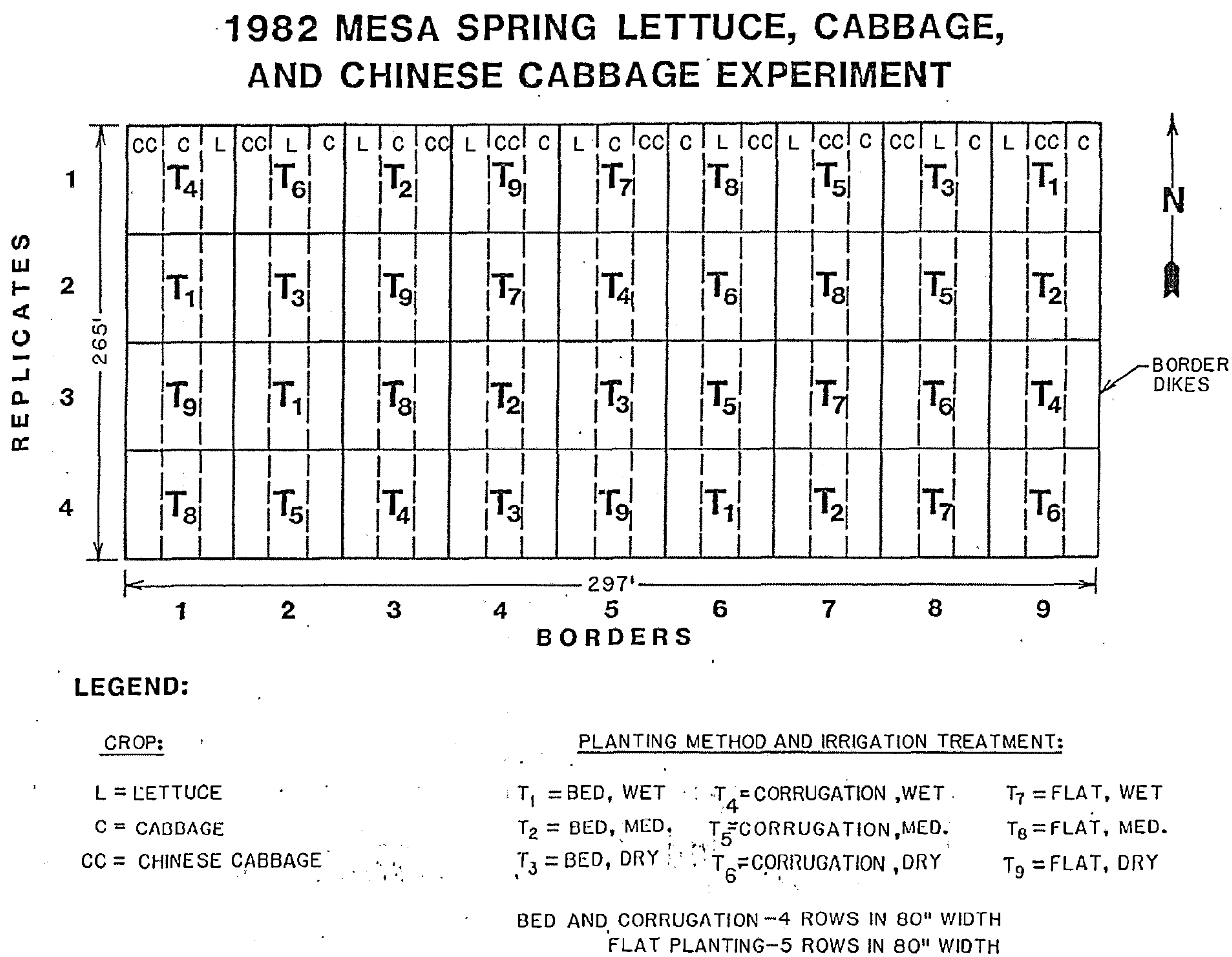

Figure 11. Plot diagram, planting method, and irrigation treatment for spring lettuce, cabbage, and Chinese cabbage at Mesa, Arizona, 1982.

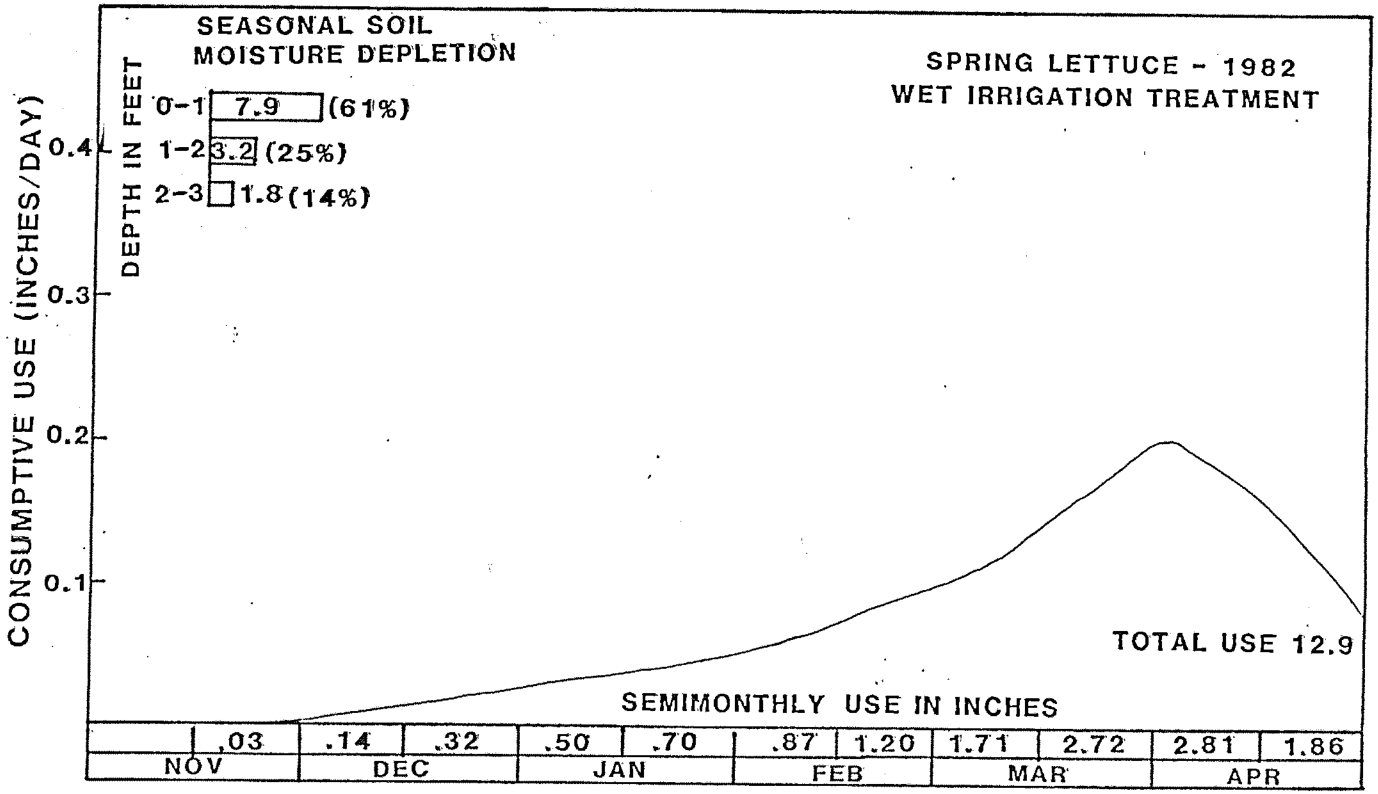

Figure 12. Mean consumptive use curve for a wet irrigation treatment on spring lettuce at Mesa, Arizona, 1982.

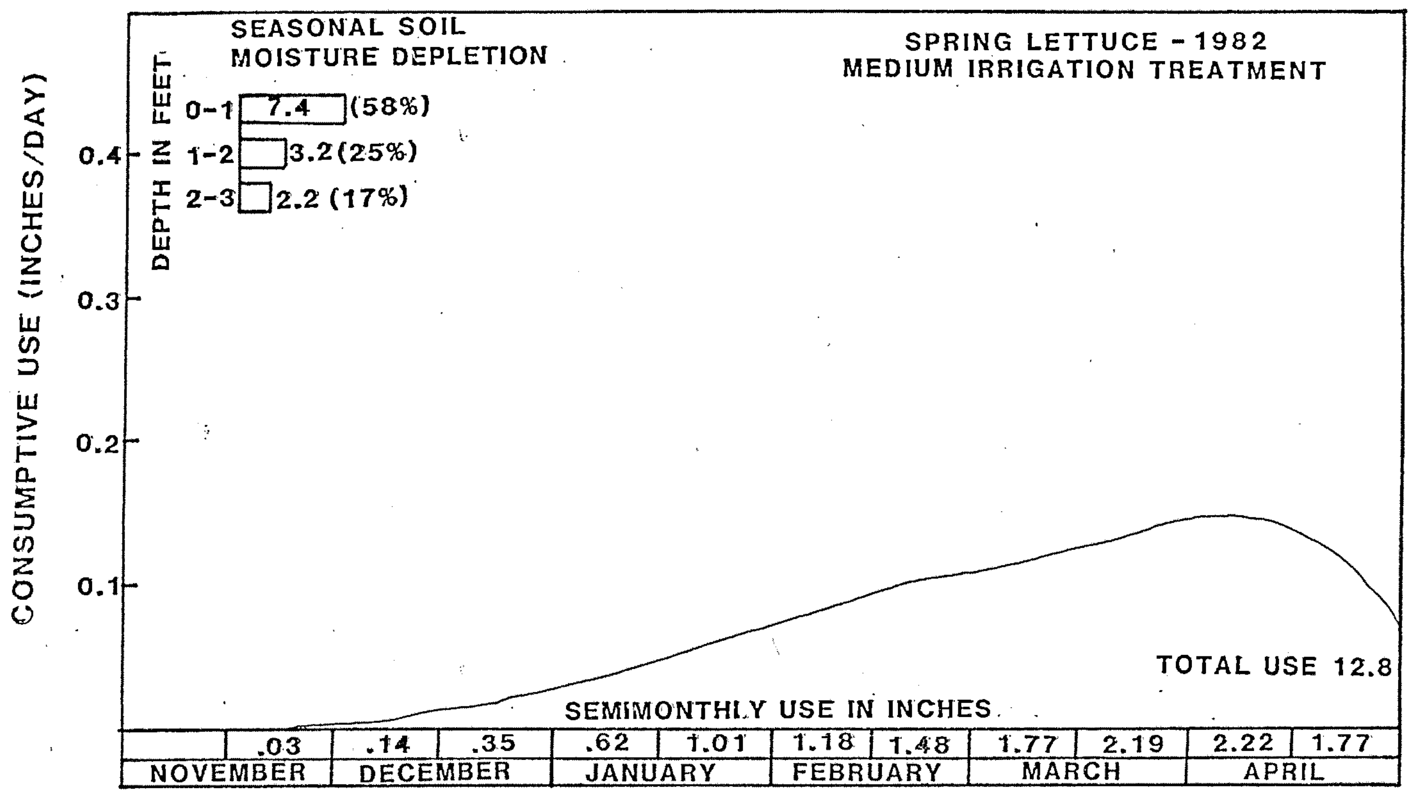

Figure 13. Mean consumptive use curve for a medium irrigation treatment on spring lettuce at Mesa, Arizona, 1982.

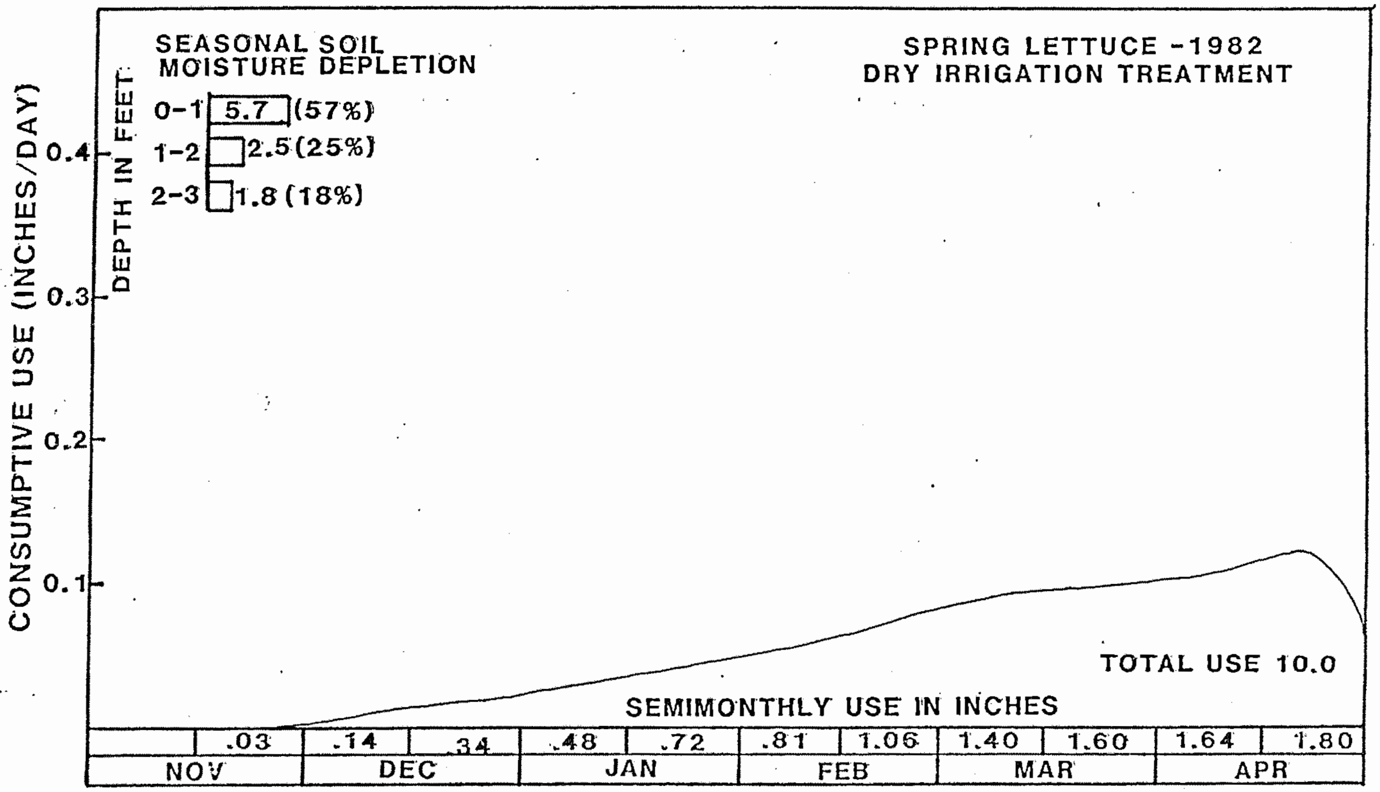

Figure 14. Mean consumptive use curve for a dry irrigation treatment on spring lettuce at Mesa, Arizona, 1982.

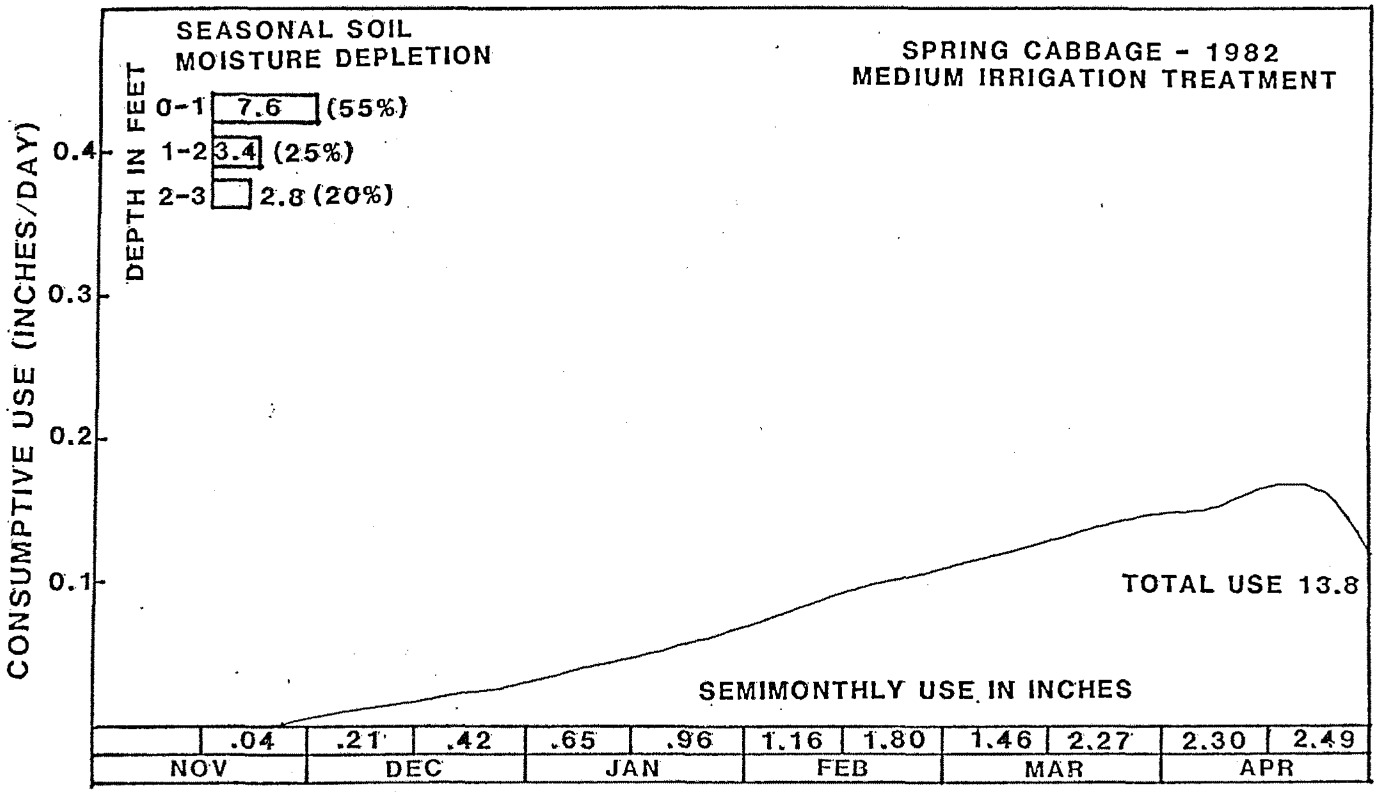

Figure 15. Mean consumptive use curve for a medium irrigation treatment on spring cabbage at Mesa, Arizona, 1982.

TITLE: TEMPERATURE ADJUSTMENT USING THE LANGELIER SATURATION INDEX IN EVALUATING CLOGGING POTENTIAL OF TRICKLE IRRIGATION WATER

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

INTRODUCTION:

Clogging of trickle emitters with carbonate precipitates is present when irrigation waters with a combination of high pH, Ca, and carbonates are used. To help in predicting the potential for such possibilities, the Langelier saturation index (LSI) has been utilized. This concept has been widely applied to water treatment process and corrosion prevention in industrial and municipal water supply lines. These lines are usually protected from the environment, but trickle irrigation lines and emitters are subject to extremes in temperatures. Nomographs and special tables [Sission, (1973), Hach, (1982)] have been prepared to provide the proper constants necessary to estimate the LSI. Programmable hand-held calculators can be also used which would provide a more convenient method for getting the index. This paper presents the various parameters needed to simplify LSI computations in the laboratory and field.

THEORY AND DEVELOPMENT:

A modified derivation from that of Langelier (1936) will be made to provide background on the components needed to obtain the LSI. The starting point is the use of the solubility product constant of $CaCO_3$, K_s, and dissociation constant of HCO_3, K_2, as follows:

$$K_s = (Ca^{2+})(CO_3^{2-}) \qquad (1)$$

$$K_2 = \frac{(H^+)(CO_3^{2-})}{(HCO_3^-)} \qquad (2)$$

Where the parenthesis enclosing the constituents implies activity. Division of equation (1) by (2) yields:

$$\frac{K_s}{K_d} = \frac{(Ca^{2+})(HCO_3^-)}{(H^+)} \qquad (3)$$

and redefining the activities of Ca^{2+} and HCO_3 in terms of concentrations where $(Ca^{2+}) = \gamma_{Ca}[Ca^{2+}]$ and $(HCO_3) = \gamma_{HCO_3}[HCO_3]$ where γ is the activity coefficient, equation (3) becomes

$$\frac{K_s}{K_2} = \frac{[Ca^{2+}][HCO_3]\ \gamma_{Ca}\ \gamma_{HCO_3}}{(H^+)} \qquad (4)$$

When the solution is in equilibrium with solid $CaCO_3$ at atmospheric CO_2 partial pressure, the measured concentration of Ca^{2+} and HCO_3 could be used to calculate (H^+) or $pH_c = -\log\ (H^+)$ which should be the same as the measured pH_m so that $pH_m - pH_c = 0$. If pH_c does not equal pH_m then a equilibrium condition is not present as far as $CaCO_3$ is concerned. Langelier (1935) arrived at a conclusion that if $pH_m > pH_c$ a supersaturated condition would exist and $CaCO_3$ could be deposited from solution, and on the other hand, if $pH_m < pH_c$, precipitation of $CaCO_3$ would not occur. Conversion of equation (3) to pK values, where pK = -log(x)

$$pH_c = (pK_2 - pK_s) + p[HCO_3] + p[Ca^{2+}] + p(\gamma_{Ca^2}\gamma_{HCO_3})$$

The components pK_2, pK_s and $p(\gamma_{Ca}\ \gamma_{HCO_3})$ are temperature dependent. The temperature of the system must be specified and the preceding parameters must be related to that temperature for estimating pH_c. Using the temperature relationship presented by Garrels and Christ (1965), the following regression equation was derived:

$$pK_2 - pK_s = 2.586 - 2.621 \times 10^{-2}\ t + 1.019 \times 10^{-4}\ t^2$$

where t is the solution temperature in degree Celsius.

The activity coefficient factor was also calculated as a function of temperature using the Debye-Huekel equation, but in this case a change of only 0.02 units was observed over the 0 to 50 C range so that the temperature function for this component was not included.

The ion activity coefficient factor is, however, concentration dependent via the ionic strength, and the relation observed by Bower et al. (196) that

$$1000\ \mu = 1.3477\ C + 0.5355$$

where μ is the ionic strength and C is the total cation concentration n This relation was used to develop the following equation for the ion acti coefficient factor:

$$p(\gamma_{Ca}\gamma_{HCO_3}) = 7.790 \times 10^{-2} + 2.160 \times 10^{-2} C - 5.477 \times 10^{-4} C^2 + 5.323 \times 10^{-6} C^3$$

RESULTS AND DISCUSSION:

Using the preceding set of equations at 51.5°C and the concentration given by Sisson (1973) of Ca = 240 ppm as $CaCO_3$ hardness, alkalinity = 196 ppm as $CaCO_3$ and total salt concentration = 400 ppm, a pH_c of 6.75 was obtained. This compares with the pH_c of 6.72 by Sisson and pH_c of 6.73 derived by the tabular method of Hach (1982). Since the measured pH_m was 7.2, a positive 0.45 is calculated from pH_c of 6.75, and indicates a tendency for $CaCO_3$ to precipitate with this water. On the other hand, if a temperature of 25°C is used, pH_c = 7.23 and the LSI = -0.03, a negative value indicating small probability for $CaCO_3$ precipitation. It was possible to use desk-top and hand-held programmable calculators to determine pH_c from the simplified equations. Results from these were similar to those obtained with the larger main-frame computers.

Field temperature measurements of trickle irrigation lines show that large diurnal temperature fluctuations can occur, especially when the lines or emitters are placed on the soil surface in direct sunlight (Figure 1). Buried lines have smaller range of temperature extremes than the exposed and follows closely the maximum temperature of the water. The observation that temperatures can be increased by 15 to 20 C and higher than ambient and that LSI is affected by such temperature changes imply that temperature can play an important role in the deposition of carbonates in trickle irrigation systems.

SUMMARY AND CONCLUSIONS:

The temperature coefficient factor was incorporated into the Langelier saturation index method for estimating the calcium carbonate precipitation tendency of irrigation water. This adaption improves the predictive ability of the saturation index approach to practical situations encountered in trickle irrigation systems. The computational approach has been simplified so that hand-held calculators can be used for computing the saturation index from the chemical analysis of the water.

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PERSONNEL: F. S. Nakayama

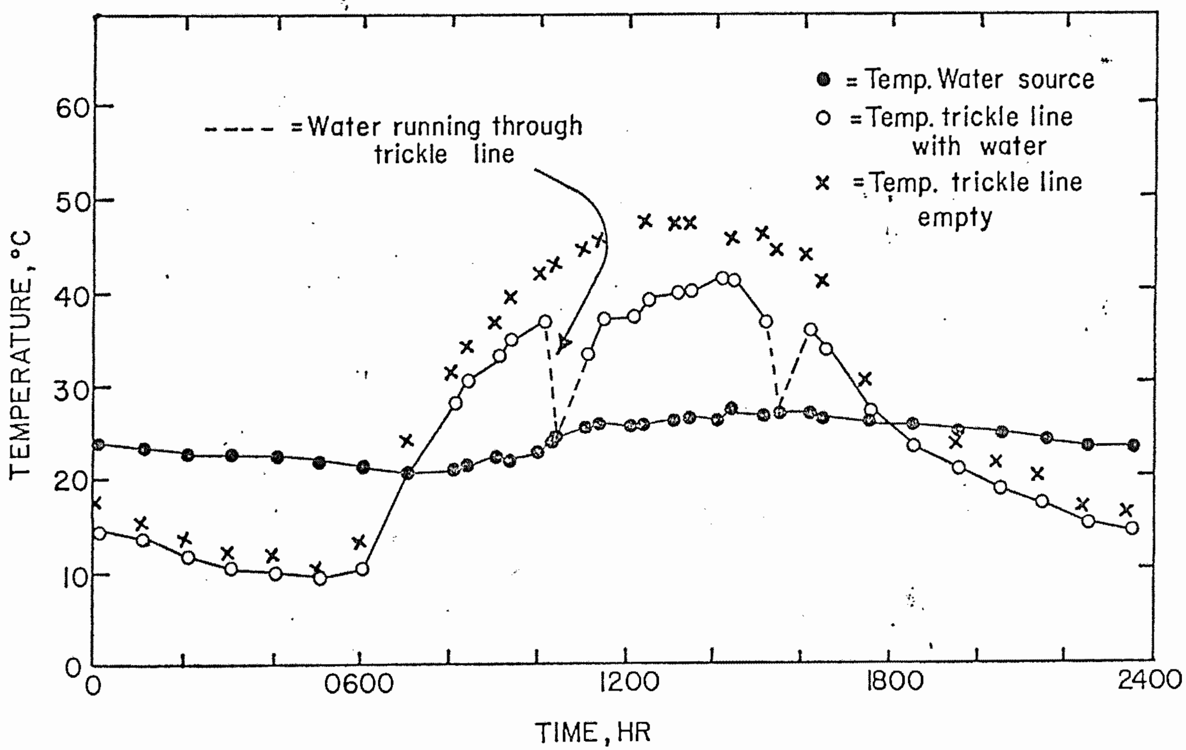

Figure 1. Temperature of buried and exposed trickle lines in the field.

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TITLE: FLOW MONITORING OF IRRIGATION WATER DELIVERIES

NRP: 20740 CRIS WORK UNIT: 5510-20740-004

INTRODUCTION:

The delivery of water to farm irrigation systems is important to the effective use of that water. It is well known that some flexibility in the water delivery is required for optimum plant/soil/water management, e.g., applying the right amount of water at the right time. Fluctuations in water deliveries and changes from irrigation to irrigation complicate the decisions of the irrigator and makes it difficult to apply the correct amount of water uniformly. Fluctuations in water deliveries (i.e., from irrigation districts) are more noticeable with on-farm systems which are being managed at high levels of efficiency and uniformity. As farmers improve their irrigation management procedures, these fluctuations become more significant. Also as irrigation districts improve their flexibility in deliveries, they may experience more transient flow conditions and thus more delivery fluctuations.

Currently, most hydrologic data are collected with float-operated mechanical chart recorders. Our experience has shown that these devices are somewhat unreliable and subject to error unless they are intensively maintained. Even so, errors of 0.05 to 0.10 feet are common. This error level is not acceptable for accurate flow monitoring. For the flumes commonly used, an error of 0.01 feet represents a 2% discharge error. Thus an effort has been made to develop more accurate, reliable methods of head detection.

PARKER STUDY:

Twenty on-farm irrigation delivery turnouts were monitored during 1980 and the data have been analyzed. Some data were lost and were supplemented with data from field observations. Irrigation district data were not in a form that was usable for checking these deliveries. The Soil Conservation Service (SCS) used these data as part of a study to determine existing on-farm water managment practices. They determined such things as irrigation efficiency, deep percolation, runoff, under irrigation, crop water use, crop yield, etc.

The data were also analyzed in terms of delivery uniformity. The charts were read with an electronic digitizer. Flow rate values were interpolated at 1/2 hour intervals to obtain statistics on delivery uniformity. The coefficient of variation, CV, for each irrigation was determined for different percentages of flow volume. Zero and/or low flow rates during rundown greatly affected the CV values. Thus we chose the CV values for 98% of the volume delivered. The 98% volume CV value for each flume was averaged by weighting according to volume delivered. These average CV values ranged from 0.04 to 0.30, with a majority ranging from 0.1 to 0.2. Time of year had no impact on CV. Delivery flow rate had a minor effect which was not statisically significant. The CV values were best correlated with location within the irrigation distict. For several types of statistical distributions, the low quarter distribution uniformity can be found from DULQ = 1-1.27 CV. The ranges of CV found here then give DULQ = 0.63 to 0.95. Data from the Salt River Project for the Eastern Canal during the summer of 1978 showed lateral efficiency ranging from 75 to 91%. It is hypothesized that the lateral efficiency is limited by the delivery uniformity.

Data have been collected for 1-3/4 years from 27 spills from the canal system in Parker Valley. The SCS is analyzing the water flow within the district to determine a water balance. Due to equipment problems, very little of these data have been analyzed. A summary of the registration errors and the amount of usable data collected is given in the 1981 Annual Report. During 1981, data were collected on only about 50% of the calendar days. This was caused by a late start, the use of old unmaintained equipment, several poor flumes and poor construction. As shown in Table 1, data were lost on roughly 15% of the calendar days during 1982. The data from 1982 can be supplemented from 1981 data for four of the sites which lowers the data lost to 10%. This analysis may be somewhat misleading. Often times, when equipment malfunctions occurred, there was no flow and no data were lost since we could tell there was no flow. If there had been flow, we would not have been able to tell how much or how long. Thus, while we lost data on 10-15% of the calendar days, we probably lost 20-30% of the flow data. An example is shown in Table 2.

The zero-setting or registration errors for the 27 off-farm sites is shown in Table 3. The recorders were registered 4 times at roughly 6-month intervals. Some settling of the structures constructed in earth channels and their stilling wells was expected but it was anticipated that after the first 6-month period, the recorders would stabilize. Riprap protection was inadequate downstream on several structures, which could have caused additional settling. If the errors in zero-setting are random errors, the mean should be close to zero. Then the standard deviation would reflect range in errors to be expected. The mean, $\bar{x}$, values of error, as shown in Table 3, are not relatively small and did not change very much over time. However, the standard deviation, s, dropped considerably after the first 6-month period. In any case, a standard deviation of 0.05 to 0.10 is more than we can tolerate for irrigation flow monitoring systems. It is not known how much of the error was caused by settling by the float/recorder mechanism and by improper or lack of careful operation.

FLOW MONITORING INSTRUMENTATION:

Open-channel flow monitoring is the key ingredient for studies as reported in the previous section, in the development of volumetric control for on-farm automated systems, and for irrigation districts or individual farming enterprises for which accurate records of delivery (rate and volume) are needed. A water depth sensing technique with electronic output is required to attain volumetric control for automated systems. This output can then be used to interface with or drive an electronic controller.

Similarly electronic output, for recording only, would be easier to handle than charts that require electronic digitizing. Hence the electronic requirement along with error and inconvenience factors associated with float operated-mechanical chart recorders led us to evaluate the methods available to detect water level and to evaluate and develop techniques for converting flow depth to flow rate. Two units were developed, using bubbler and pressure transducer techniques for sensing water head. One uses the so-called "double bubbler" and the other a single bubbler with offset correction.

Water Depth Detection Methods

Numerous methods are available for detecting water level and were reviewed by Hall (1978). Methods can be classified according to the type of measurement they provide, either point or continuous (output over broad head range). Continuous measurements are required for our application. Continuous measurement methods can be further subdivided as either contact or non-contact devices. Examples of contact methods are capacitance and conductive probes and float-operated potentiometers. Non-contact types include bubbler-pressure transducers, radiation, and sonic systems. Contact methods have the disadvantage of becoming coated with chemical precipitates which may change the calibration. This is especially important when fertilizers are injected into the irrigation water. In our application, the sensing equipment will be adjusted or calibrated at the time of installation and must operate reliably thereafter without continual adjustment or maintenance. Hence we felt that our choice of depth sensing methods was reduced to sonic devices or pressure transducers coupled with bubblers. Generally, sonic devices, are easy to install and can meet our accuracy requirements, but are too expensive for monitoring on-farm irrigation water deliveries. With this in mind we have pursued development of a flow monitoring system which uses the bubbler and pressure transducer for depth sensing and a programmable hand-held calculator which controls the monitoring of the transducer and converts head measurements to flow rate.

Head Detection Accuracy Required

Calibration accuracy is about ±2 to ±3% for broad-crested weirs (b-c-w) and critical flow flumes (Replogle 1974, and 1975). The discharge (q) can be predicted from upstream water depths (h) to within about ±0.5% of actual when a power function ($q=ah^b$) is fitted to the flume calibration data for flow ranges from 10 to 30 ft^3/s. Using representative power function coefficients (a and b) for the weirs and flumes, the 2% accuracy translates into a vertical detection requirement as shown in Table 4. Except for the lower flows of the b-c-w a vertical detection accuracy of ±0.01 ft would be adequate to stay within 2% of the actual flow while detection accuracy would approach ±0.02 ft for the critical-flow flumes at high flow rates.

Bubbler and Pressure Transducer

The bubbler unit is one of the oldest and simplest level measuring devices, wherein a tube or pipe is placed at the bottom of the water column to be measured (zero of a flume in our case). Air flowing through the tubing causes bubbles to escape through the water. The air pressure at the end of the tube where the air escapes corresponds to the hydraulic head of the water and can be sensed with a pressure transducer, which produces an electrical analog signal proportional to head. The pressure transducer can be located remotely from the flow metering device and bubbler (i.e., at the controller if desired). This has the advantage of centrally locating all electronic equipment with only the bubbler contacting the water. The distance between the bubbler and transducer is essentially unlimited if dual tubes are used; one for supplying the bubbler and the other, teed to the first near the bubbler, for sensing the pressure. For short distances, single tubes from the transducer to bubbler can be used since pressure losses will be small. Tubes can be very small (1/8 in. ID) when dual tubes are used since pressure losses are not a concern. A flow control valve is required to provide about 5-10 bubbles per second at the bubbler.

Centrally locating the electronic equipment eases the task of environmental protection. Transducers are, however, many times drastically affected by temperature and generally to a lesser extent by continual use, e. g., stress-strain factors. These factors lead to transducer calibration changes that may be reflected either as gain (output/unit head change) or offset (output at atmospheric pressure) errors. Transducers can be temperature compensated but still may not meet our required detection accuracy. Errors associated with an inexpensive pressure transducer (rated at a nominal 25 mv span output for 25-inch water head) are illustrated in Fig. 1. Transducer output was checked over the entire range with 50°F and 120°F readings compared to those obtained at 80°F. The voltages were translated to equivalent error in the head reading. Errors ranged from underestimating head by as much as 0.08 ft. to overestimations of about 0.11 ft. at low head. For this particular transducer readings are very accurate (regardless of temperature) near the upper pressure limit. Both gain and offset changed as temperature changed, Table 5. Other transducers could be selected that would be more temperature stable.

Transducer Adjustment Techniques

Rather than rely on temperature compensation techniques, which may be expensive, transducer error can be controlled by physically checking the transducer at known pressures and performing appropriate adjustments. The physical requirements for attaining the transducer readings needed are illustrated in Fig. 2. Procedures include (a) a single bubbler located at the flume zero, (b) two bubblers, one at the flume zero and one at a reference head (h_k), and (c) two bubblers with a known pressure differential (Δh). A voltage response curve for a pressure transducer is used in Fig. 3 to illustrate the transducer output-head measurements and in characterizing the three procedures. Note that all procedures assume that the voltage response of the pressure transducer is linear, which has been the case for those we have tested. All of the procedures require transducer readings for various bubbler configurations and at atmospheric pressure, hence switching procedures are required. Appropriate voltage-head readings, assumptions that can be made in handling the transducers (simplifying but generally at the expense of accuracy), and resultant head prediction equations are shown in Table 6. The algebra required in calculating the pressure head (h_1) results from considering the line slope (b) which is the transducer gain and is illustrated also in Fig. 2 for all three bubbler configurations.

The basic assumption when using the single bubbler is that the transducer gain (b) does not change from that found when precalibrated. Offset adjustment is illustrated in Case 3, Table 6. For the transducer data illustrated in Fig. 1, offset correction would only result in improved accuracy at low heads, with accuracy sacrificed at high heads. Hence such a correction would be of little value.

Two bubblers, one at the flume zero and the other at some reference head, can yield good head measurement (Cases 4 and 5) and if corrected for offset (Case 6) the accuracy would be excellent and independent of the transducer, since the transducer is essentially precalibrated each time. Case 4, where the offset voltage is ignored ($V_o = 0$), can be reasonably accurate if the reference head (h_k) is near h_1. Accuracy of ±0.01 ft. could be maintained for the transducer of Fig. 1 if h_k were within about 0.15 ft. of h_1. For many applications, especially when delivering water for irrigation, such a tolerance would be practical. Maintenance of the reference head in the field is the main disadvantage and in many instances would be impractical.

The requirement of a reference head, to essentially replace h_k, can be circumvented by obtaining two pressure readings with a known pressure differential. When the pressures are referenced to atmospheric we refer to the procedure as the double bubbler system (Case 9 of Table 6). The pressure transducer is being recalibrated each time a set of readings are taken. Calculation of h_1 depends on the distance between the bubblers (Δh) with the shallow bubbler at the flume zero. Construction of a double bubbler to any specified Δh is not difficult and once installed will require little maintenance. The accuracy of such a system is independent of the pressure transducer (inexpensive, nontemperature compensated is satisfactory). An example of the error in head recorded using the double-bubbler system is shown in Fig. 4. These error values were developed from the same data set used in Fig. 1. Essentially all errors were within ±0.003 ft. which is about 1/3 that required (±0.01 ft), and were not temperature dependent. The manometer system used for measuring actual head may have contributed to the apparent trend in error with head. Note the error scales between Figs. 1 and 4 are different by a factor of ten.

HP-IL Controlled Double-Bubbler System

A flow monitoring system was developed utilizing the double-bubbler system and a hand-held calculator controlled data acquisition and control system.

The physical setup for the flow monitoring system is shown in Fig. 5. It consists of: 1) an air supply, 2) two flow control valves for setting the bubble rate for each bubbler, 3) a double-bubbler with two outlets set a fixed distance apart (the upper bubbler must be set at the zero of th flume), 4) three 2-way solenoid valves for switching the pressure lines to the transducer, 5) a pressure transducer, 6) a power supply for transducer excitation, and 7) the HP-IL system for switching valves, taking voltag readings, computing head and volume, storing and recording data and controlling operations.

The HP-IL (interface loop) system is a Hewlett Packard communication system that is compatible with a number of Hewlett Packard devices and controllers. We are using the HP41CV calculator as the controller whic requires an interface module to communicate on the IL loop. Voltage readings are made with a digital multimeter (analog to digital conversion of transducer output). The calculator controls the meter; e.g., sets up the voltage range, number of digits precision, and triggers the meter t make a voltage reading.

The three valves in the system are controlled by means of a custom made switching unit. The switching unit is controlled from an HP-IL converter unit. A schematic of the switching unit is shown in Fig. 6, and the communication lines used with the HP-IL converter for switching the valves via the switching unit are listed in Table 7. A summary of the switching unit operation follows:

<u>Initial State</u> — The HP41CV calculator is programmed, power is turned on to the switching unit, and all units within the IL system are powered up and idling. All valves are off.

<u>Beginning Operation</u> -- To activate one solenoid valve an alpha-alphanumeric character is entered into the alpha register of the HP41CV calculator. The HP41CV sends (through a series of commands) the ASCII 8 bit code of the alphanumeric character to the HP-IL converter in a serial fashion (one bit at a time). The IL converter receives the serial information and converts the 8 bit serial pattern information to an 8 bit parallel output to the latches. The switchbox uses the low 4 bit lines of the 8 bit paralleled output of the HP-IL converter. The HP-IL converter, upon transmitting its output, also sends a load signal after all 8 output lines have been set to their correct output state. Each latch will lock into its buffer the present output state of the IL converters respective line when the load line is pulsed. At the end of the load line pulse the latch will present and hold what has been latched into each buffer to the output lines of each latch. Each latch gate has two outputs. One output is the same polarity as the input that has been latched. This output line drives the series transistor switch. The second output of each latch is an inverted output of the input signal that has been latched. This second output drives a LED light indicating the valve number that was turned on.

When the series transistor switch is turned on, current flows through the transistor switch and the solenoid valve is activated. Latching a logic state '1' into the latch turns the transistor switch and valve on. A logic state '0' will turn the transistor switch and valve off. The current state of the latch is not allowed to change until the load line is again pulsed at which time the present state of the IL converter output is again loaded into the latch buffers. The switching unit contains four latches and four series transistor switches for four solenoid valves. One load activates all four buffers at one time. The switch box also contains a 5-volt regulator which is fed from the supply voltage source. The output of the 5-volt regulator supplies power for the HP-IL converter and the latch device. The solenoid valves are powered by the supply voltage source (12 vdc).

A timer module is used to activate the calculator to take periodic readings at 2-minute intervals. The timer module is also useful for delaying voltage readings until after the valves are switched and the pressure has stabilized. A printer and cassette tape drive were added to the unit to record and store data. The initial system was set up for use by the Fifield Land Company of Brawley, CA. Thus we provided a printout which gave the cumulative volume at 10-minute intervals and the average flow rate over the previous hour. Information for an irrigation was provided on starting and stopping times, flow duration, and total volume delivered (Table 8). All of the data obtained by the Fifield monitoring system will be stored on cassette tapes for flow delivery analyzes here at the U. S. Water Conservation Laboratory.

A schematic of the double bubbler and bracket used for attachment to the stilling well are shown in Fig. 7. The two bubblers were constructed using 1/8-in. (OD) stainless steel tubing. Two inch tubes were press fit through 1/4-in. galvanized pipe for holding the bubblers. Distance between the bubblers was precisely set at 0.5 ft. Some of the dimensions given were specifically related to the stilling well and canal dimensions. In our case the stilling well was 8-in. dia. constructed of schedule 80 PVC. The trapezoidal canal dimensions were: 3-ft. deep, 2-ft. bottom width, and 1:1 sideslope.

All items outside the stilling well can be housed in a standard 20-in. x 20-in. x 6-in. instrument box. Such a unit could then be either permanently located at a flume site or could be portable for moving from site to site. The system to be used on the Fifield Land Company farms will be portable. The entire unit weighs less than 30 lbs. when a fiberglass enclosure is used. A parts list, part numbers where appropriate, and our cost for the various components of the initial unit are shown in Table 9.

The system has been operated and tested extensively in the laboratory where operating temperatures can be accurately maintained over a wide range (40°F to 120°F). All tests have been satisfactory. A limited number of irrigations have been monitored in the field. Extensive field use is planned during 1983. Efforts will be made during 1983 to improve the system especially considering problems associated with (1) AC power requirement to run HP devices and fish tank aerator, (2) air and electrical connections, (3) packaging entire system for portability, (4) voltage supply to pressure transducer, and (5) cost.

Dedicated Electronic System - Transducer Offset

An open-channel flow-monitoring system was developed by Mr. Jonathan R. Dust for partial fulfillment of the requirements for a Master of Technology degree from Arizona State University. The system corresponds to Case 3 of Table 6, in which the pressure transducer is adjusted for offset changes only and assumes gain stability. The system was aimed at meeting open-channel flow monitoring requirements similar to those specified in the Arizona groundwater legislation. The system requirements were that the flow rate and volume delivered could be displayed for use by the farmer and at a marketable unit cost (under $500). The prototype unit used a thermistor compensated monolithic resistive bridge pressure transducer connected to an offset error compensation circuit. To simplify the design the microprocessor based unit did not calculate flow rate from the power function but used a head-flow rate matrix look up table, specific for each flume. The unit was described in detail by Dust in his Master's Thesis titled "Open Channel Flow Sensor and Totalizer Unit," Arizona State University, College of Engineering, Division of Technology.

Under limited testing the unit operated as designed with measurment error less than or equal to 5%. The system will be extensively tested in the laboratory to fully evaluate the stability over a broad temperature range. If satisfactory the system will be redesigned to reduce unnecessary components and unit packaging would be undertaken.

SUMMARY AND CONCLUSIONS:

Data collected from on-farm water deliveries for 20 sites on the Colorado River Indian Reservation during 1980 and 1981 have been analyzed. The average coefficient of variation for these sites ranged from 0.03 to 0.30. This corresponds to low quarter distribution uniformities ranging from 0.96 to 0.63. The coefficient of variation was related to the location within the delivery system but was not correlated with time of year or flow rate. From this data we hypothesize that the lateral efficiency is limited by the delivery uniformities. Data are still being collected on spills from the delivery system for this study. Field work will be completed on this project in January or February 1983. Because of a late start in 1981 and numerous equipment problems only about 50% of the flow data was usable during 1981. During 1982, a number of problems remained unresolved, however data were lost on only 15% of the calendar days. At several sites, combining data from the two years resulted in data lost on only 10% of the calendar days. Some of this data however are inaccurate due to poor flume design.

A unique flow monitoring and totalizing system for use with a variety of flumes and weirs was developed. The system uses an inexpensive pressure transducer and bubbler scheme for water head sensing coupled with a digital multimeter controlled by a programmable hand-held electronic calculator. A recently developed (commercial) interface loop between the calculator and various peripheral devices (multimeter, converter, printer, and tape recorder) made such a system possible. The uniqueness of the system centers on the use of a double bubbler to provide a scheme for automatically calibrating the pressure transducer (offset and gain compensated). The program for control of the system and calculation of flow rate and volume of water delivered was developed and one monitoring system was built during 1982. The system, when laboratory tested easily met our flow detection accuracy requirements.

A flow monitoring system, utilizing a pressure transducer and single bubbler, was developed with dedicated electronic components. The pressure transducer is adjusted for offset changes, relying on the temperature compensation of the pressure transducer for gain stability. Further work will include testing the unit for temperature effects, checking the accuracy of a look up table (flow versus head) and redesigning to reduce unnecessary components. The system is aimed at meeting open-channel flow monitoring requirements similar to those specified by Arizona groundwater legislation.

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PERSONNEL: A. R. Dedrick and A. J. Clemmens

Table 1. Summary of lost data for Parker, Arizona off-farm study.

Site	Recording Period	No. of Days of Lost Data in One Year 1982 Only	Combined	Comments
52	2/03/82-1/12/83	6		Excellent
53	"	16		Good
54	6/23/81-6/04/82	216	(30±)	Poor (new flume installed on 6/23/81, washed out 6/4/82)
55	2/03/82-1/12/83	56		Fair (vandalized, new recorder installed with wrong gears, still got good sample)
56	"	7		Excellent
57	"	17		Good
58	"	[83]		Poor (bad clock)
60	"	7		Good
61	"	6		Good
62	"	37		Fair
63	"	29		Fair (weir poor at high flows)
64	"	17		Good
66	"	37		Fair (clock runs short?)
67	"	9		Good
68	"	0		Excellent
69	"	32		Fair
70	"	5		Excellent
71	3/18/81-6/23/82	104	(30±)	Poor (new flume installed on 6/23/81, still poor, damaged 6/82)
72	8/06/81-8/05/82	65	(45)	Poor (fair)
73	2/03/82-1/12/83	30		Good (lost data, easily est.)
74	"	73		Good (lost data, easily est.)
75	"	46		Good (bad flume!)
76	3/27/81-3/03/82 + 10/14/82-1/12/83	99	(30±)	Poor (good)
78	2/03/82-1/12/83	[70]		Poor
80	"	[>150]		Poor (bad site, stilling well knocked over and replaced)
81	"	11		Fair (seldom flowed)
82	"	20		Excellent
(27 sites)	Ran 334 days between dry ups.	1248	(899)	

Avg lost data - 46 days - avg. 82 only 14%
- 33 days - with some 81 data 10%

Out of 2 years - insufficient data from 58, 78, 80, 55
- poor flumes 54 (1/2), 71, 75, 80
- never monitored 77, 79, other drains in system

Table 2. Example of calculations of lost data, Site #55. All data would have been collected, but the clock had the wrong gears. Data summary is from 3/2/82 to 11/23/82.

	Number of Days				
	Readable Data	No. Data	Estimated Data	Total	Not Used in Estimate
Flow	36	56	28	64	0
No flow	111	60	88	199	71
	147	116	116	263	334

Flow occurred on 36 of 147 days or 24.5%.

24.5% of 116 = 28 days or half of the days for which we had no time record.

Total days of flow is approximately 36 + 28 = 64.

Thus for actual flow, we lost 28/64 = 44% of data, while estimate shows 56/334 = 17%.

This difference (44% vs 17%) is magnified since this flume ran less than 20% of the time.

Table 3. Registration errors (in feet) for Parker, Arizona off-farm study.

Site		Dates 5/81-12/81	12/81-8/82	8/82-1/23	Comments
Flumes in Channels (V and BCW)					
42		-0.045	----		V-shaped unless noted otherwise
52		+0.010	-0.015	-0.001	
53		-0.051	+0.040	-0.012	
55		----	-0.116 (0.5)	-0.100	
56		-0.010	-0.103	+0.060	
57		-0.010	+0.037	-0.010	
58	(0.5)	-0.018	+0.020	-0.125	
60	(0.5)	0.000	0.000	-0.005	
61		-0.260	-0.040	-0.040	
62	(0.5)	-0.010	-0.020	-0.010	
64		-0.115	-0.120	-0.060	Throat obviously settled
66	(0.5)	-0.040	-0.280	-0.030	
67		+0.030	0.000	+0.005	BCW
74		----	-0.015 (0.5)	+0.095	
76		-0.010	+0.004	-0.158	
78		+0.330	+0.020 (0.5)	+0.023	
82		-0.215	----	(-0.190)	Not reached first time (pressure tap improperly located)
	$\bar{x}$ =	-0.028	-0.040	-0.025	
	s =	0.129	0.084	0.066	
Others					
*54		-0.140	----	----	Sill in pipe (kept washing out)
63		+0.043 (0.5)	-0.053	----	Sharp crested weir (turbulent at high flow
68		+0.100	0.000	+0.030	Sill in pipe
69		----	-0.062	----	Sill in pipe (drum loosened and was freewheeling)
70		0.000 (0.5)	----	-0.020	Sharp crested weir
*71		0.000	0.000 (0.5)	0.000	Sill in pipe (sheet metal flume bent up, too turbulent)
72		-0.020	-0.008	-0.010	Sill in pipe
73		----	-0.009	0.000	Sill in pipe
*75	(0.5)	0000	----	----	Sill in pipe (not functioning, too turbulent)
*80	(0.5)	-0.125 (0.5)	+0.024	0.000	Sill in drop box (too turbulent)
81		+0.030	-0.020	-0.026	Sill in chute
	$\bar{x}$ =	-0.008	-0.016	-0.004	
	s =	0.077	0.029	0.018	

*Flumes did not function well.

[Overall $\bar{x}$ = -0.027]
[s = 0.085]

Table 4. Head detection accuracy required with broad-crested weirs and critical-flow flumes to maintain 2% accuracy at various flow rates.

Flume type	Flow rate, ft^3/s 10	20	30
	(ft)	(ft)	(ft)
Broad-crested weir	±0.009	±0.013	±0.017
Critical-flow flume	±0.012	±0.017	±0.021

Table 5. Gain and offset for pressure transducer tested at three air temperatures. Data are for same transducer as reported in Fig. 1.

Air Temperature	Offset	Gain
(°F)	(mv)	(mv/ft)
50	-4.80	19.17
80	-3.23	18.55
120	-1.09	17.71

Table 6. Procedure summary for detecting water head (h_1) with a pressure transducer and variously arranged bubblers. Included are transducer output correction techniques, resultant head prediction equations, required voltage measurements, and switching requirements. Refer to Figs. 2 and 3.

Bubbler System	Case Number	Offset Assumption	Head Prediction Equation, h_1	When Offset Measured 1/	Conditions Measured While Monitoring: Number 2/	Conditions Measured While Monitoring: Type	Switching Required 3/
a) Single Bubbler @ Flume Zero	1	$V_o = 0$	$h_1 = \frac{V_1}{b}$	Not	1	V_1 @ h_1	No
Gain assumed constant (precalibrated)	2	V_o = constant = V_{oc} 4/	$h_1 = \frac{V_1 - V_{oc}}{b}$	PC	1	V_1 @ h_1	No
	3	$V_o \neq$ constant	$h_1 = \frac{V_1 - V_o}{b}$	WM	2	V_1 @ h_1 V_o @ $h = 0$	Yes
b) Two Bubblers One @ Flume Zero One @ Reference Head	4	$V_o = 0$	$h_1 = \frac{V_1}{V_k} h_k$	Not	2	V_1 @ h_1 V_k @ h_k	Yes
Gain adjusted while monitoring	5	V_o = constant = V_{oc}	$h_1 = \frac{V_1 - V_{oc}}{V_k - V_{oc}} h_k$	PC	2	V_1 @ h_1 V_k @ h_k	Yes
	6	$V_o \neq$ constant	$h_1 = \frac{V_1 - V_o}{V_k - V_o} h_k$	WM	3	V_1 @ h_1 V_k @ h_k V_o @ $h = 0$	Yes
c) Double Bubbler Two Bubblers at Fixed Distance Apart (Δh), One @ Flume Zero	7	$V_o = 0$	$h_1 = \frac{V_1}{V_2 - V_1} \Delta h$	Not	2	V_1 @ h_1 V_2 @ $h_1 + \Delta h$	Yes
	8	V_o = constant = V_{oc}	$h_1 = \frac{V_1 - V_{oc}}{V_2 - V_1} \Delta h$	PC	2	V_1 @ h_1 V_2 @ $h_1 + \Delta h$	Yes
Gain adjusted while monitoring	9	$V_o \neq$ constant	$h_1 = \frac{V_1 - V_o}{V_2 - V_1} \Delta h$	WM	3	V_1 @ h_1 V_2 @ $h_1 + \Delta h$ V_o @ $h = 0$	Yes

1/ PC - Precalibration, WM = While Monitoring
2/ Number of [illegible] ssure [illegible] itions measured [illegible] termi [illegible]
3/ Valve switching required to determine h_1
4/ V_{oc} is the precalibrated offset voltage.

Table 7. HP-IL communication lines used with HP-IL converter for switching valves with switching unit. (See Fig. 6).

Output Lines HP-IL	Tied to Latch
Pin 1 GRN	GRN
Pin 6 RDY1	GRN
Pin 7 GRN	GRN
Pin 11 DACI	GRN
Pin 33 GRN	GRN
Pin 3 PWR	PWR + 5 VDC
Pin 31 PWR	PWR + 5 VDC
Pin 29 DAO	D1A
Pin 30 DA1	D2A
Pin 27 DA2	D1B
Pin 28 DA3	D2B
Pin 5 DAVO	Latch (Load line)

Table 8. Example printout for an irrigation using the HP-IL controlled double-bubbler system.

```
IRRIGATION STARTED AT
11.34            11.08 1982

TIME     AC-IN        CFS
11.40      2.5        26.2
11.50      6.8        26.0
12.00     11.0        25.2

12.00     11.0        25.4

12.10     15.2        25.7
12.20     19.4        25.0
12.30     23.6        25.4
12.40     27.9        25.6
12.50     32.1        24.9
13.00     36.3        25.6

13.00     36.3        25.5



 6.10    484.5        25.8
 6.20    488.6        25.7
 6.30    492.8        24.4
 6.40    496.9        25.0
 6.50    501.1        25.5
 7.00    505.2        26.8

 7.00    505.2        25.1

 7.10    509.4        25.6
 7.20    513.7        25.9
 7.30    517.8        24.7
 7.40    522.0        15.6

IRRIGATION COMPLETED AT
7.50             11.09 1982

TOTAL VOLUME DELIV AC-IN
                  525.80

DURATION HR.MIN
20.16
```

Table 9. Components of HP-IL double-bubbler monitoring system, part numbers, and costs.

	Component	Part Number or Description	Cost
(1)[1/]	HP41CV		$274
(2)	Timer Module	PN 82182A	64
(3)	Interface Module (HPIL)	PN 82160A	104
(4)	Ditigal Multimeter (Option 326)	PN 3468A	787
(5)	Converter	PN 82166A	168
(6)	Thermal Printer	PN 82162A	411
(7)	Digital Cassette Drive	PN 82161A	457
(8)	Pressure Transducer	Foxboro PN 1700-07-01-300-5 20 mv span @ 12 vdc excitation, 25" H_2O	75
(9)	Pneumatic 2-way Valve (3)	General Valve, 3-116-900 12 vdc solenoid operated VAC-20 PSI	54
(10)	Flowmeter (2)	Dwyer, RMA-1-SSV Range 0.05-0.5 CFH	36
(11)	Switching Unit	Custom made to control valve from IL converter	Unknown

<u>Other Miscellaneous Items</u>

Power Supply (if AC System)	90
Invertor (if DC supply)	70
Air Supply (aerator)	9
Double Bubbler/Bracket, custom made	Unknown
Stilling Well and Cover	40
Water-Dust Proof Enclosure	180
Marine Battery (100 + Amp Hrs)	90

1/ Refer to Fig. 5.

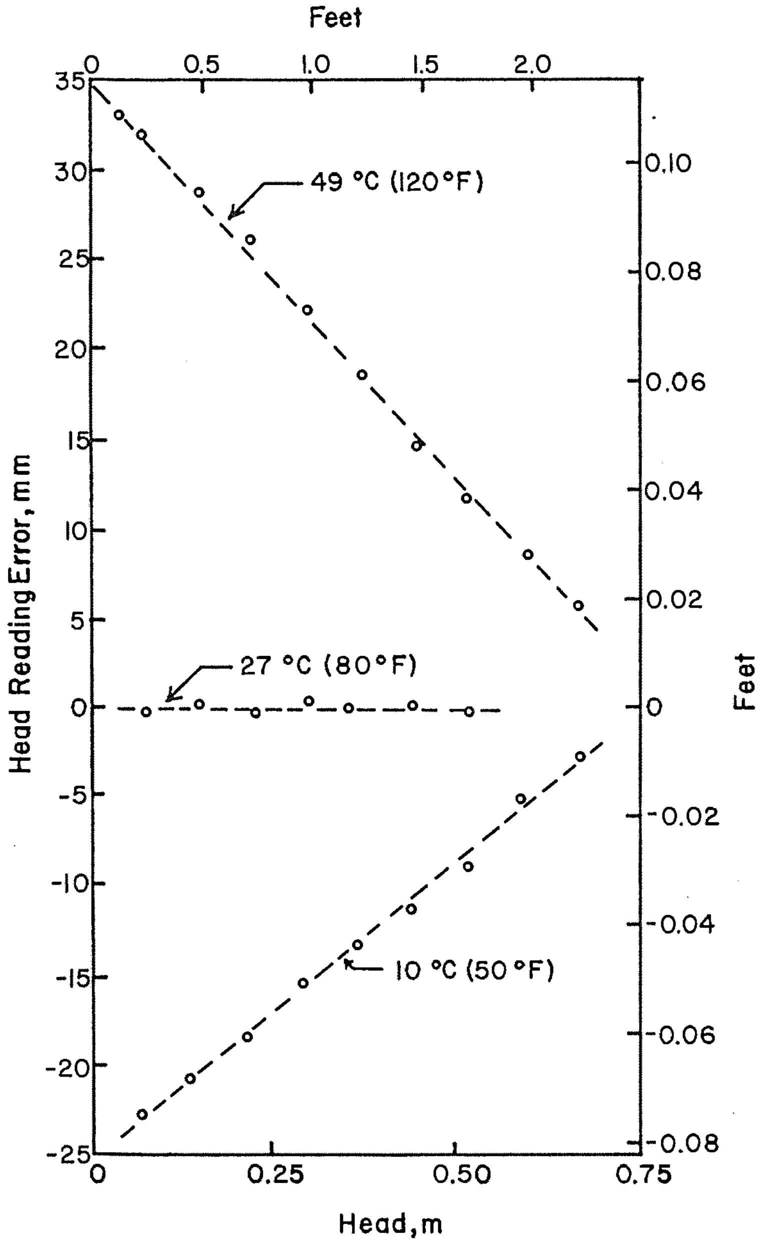


Fig. 1. Errors in head readings from pressure transducer based on average calibration at 27°C.

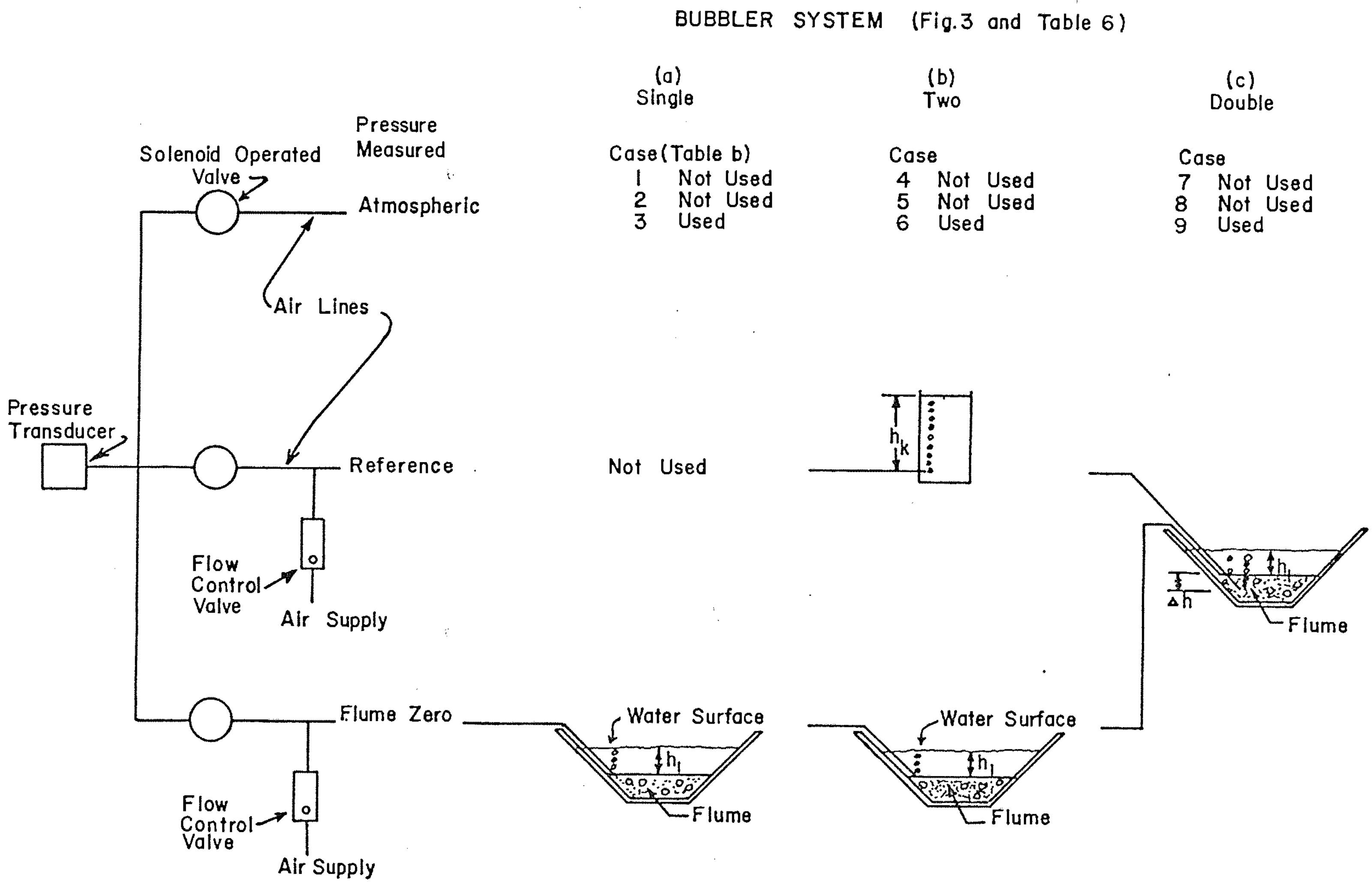


Fig. 2. Procedures for adjusting pressure transducer output to compensate for either offset and/or gain errors. All techniques require mechanical switching of valves and all procedures assume a linear transducer voltage response.

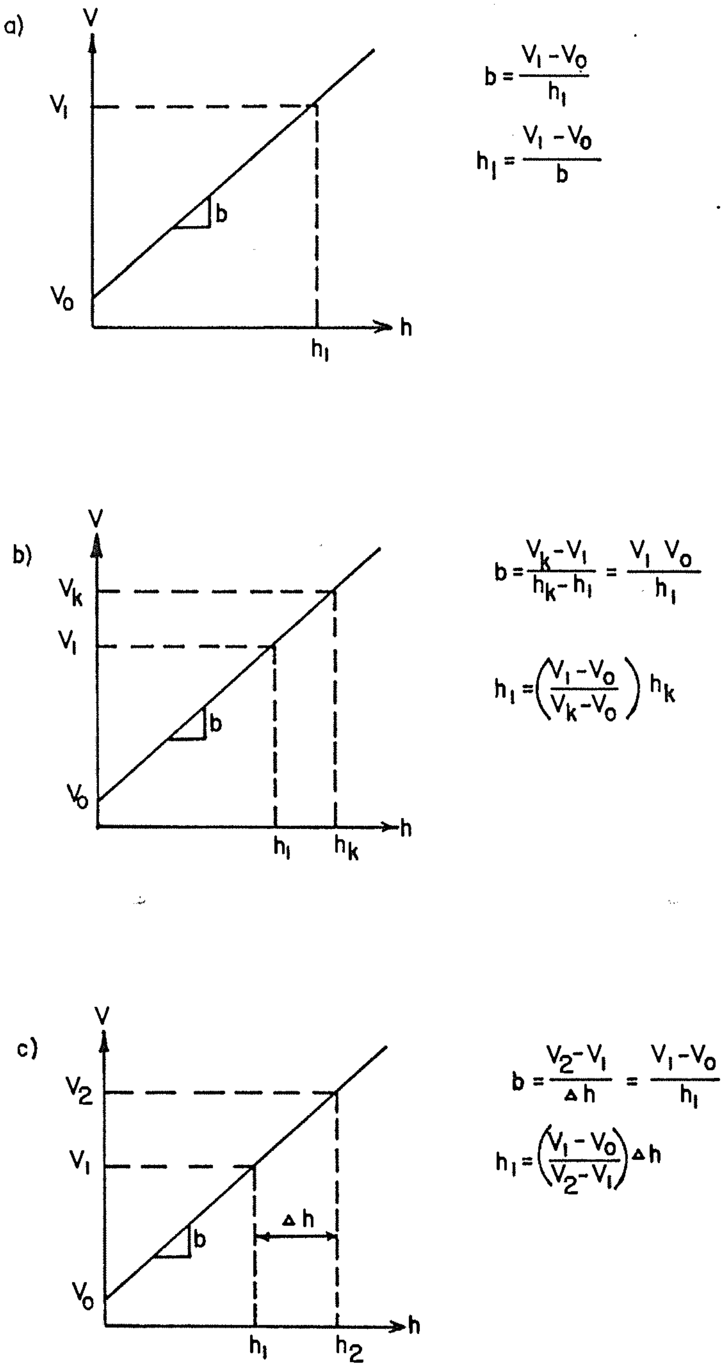


Fig. 3. Typical voltage response for a pressure transducer with voltages used in characterizing three bubbler-pressure transducer correction procedures.

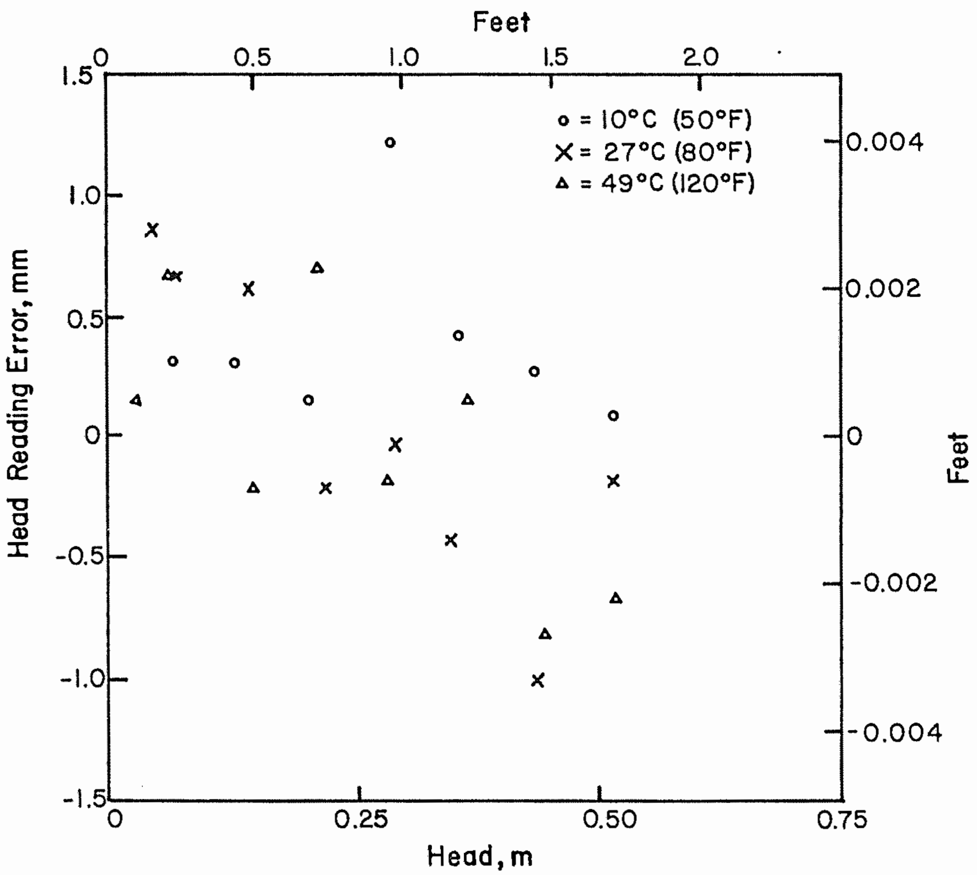


Fig. 4. Errors in head reading from pressure transducer with double-bubbler system.

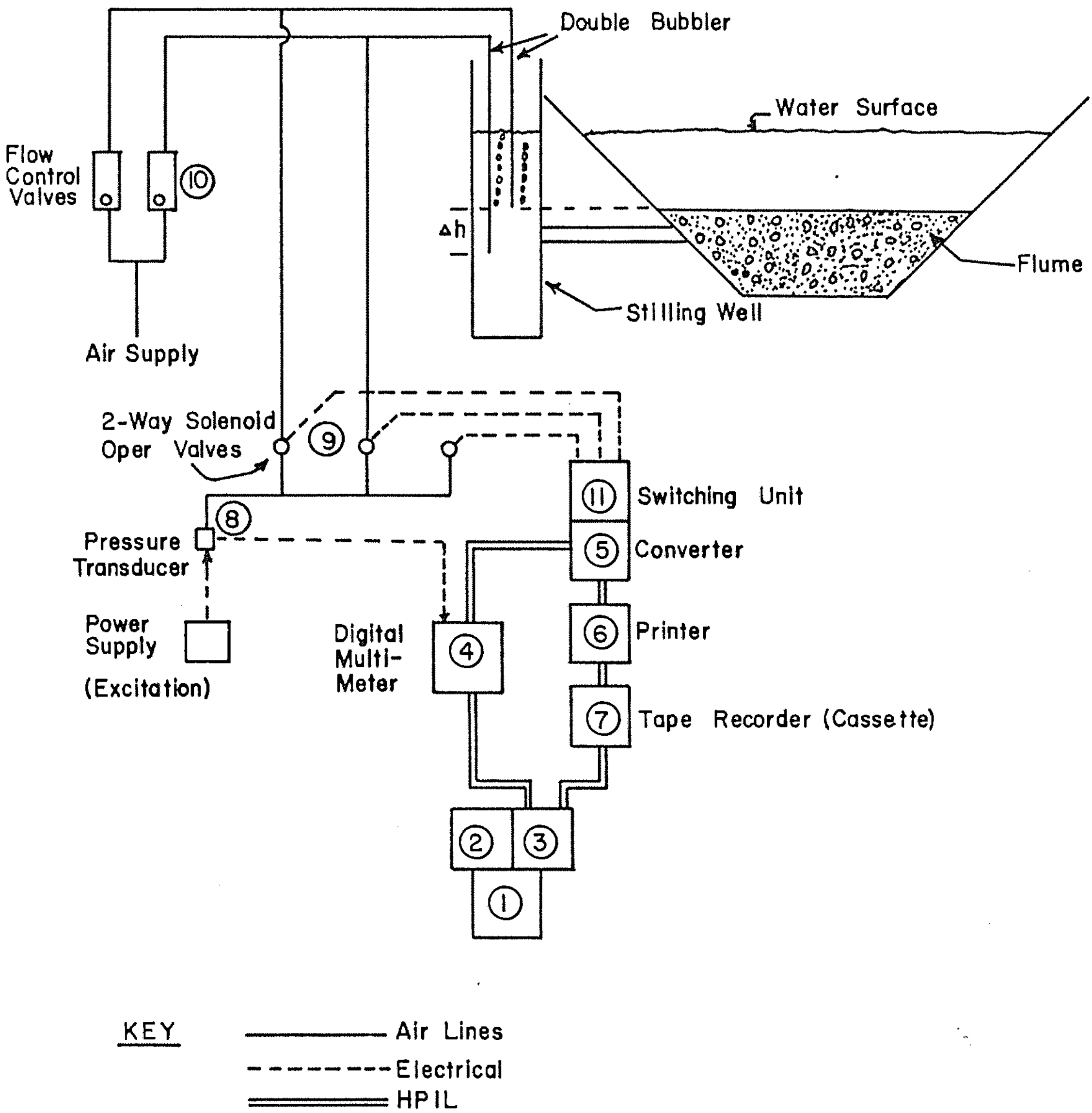


Fig. 5. Layout of double-bubbler monitoring system. See Table 9 for component details.

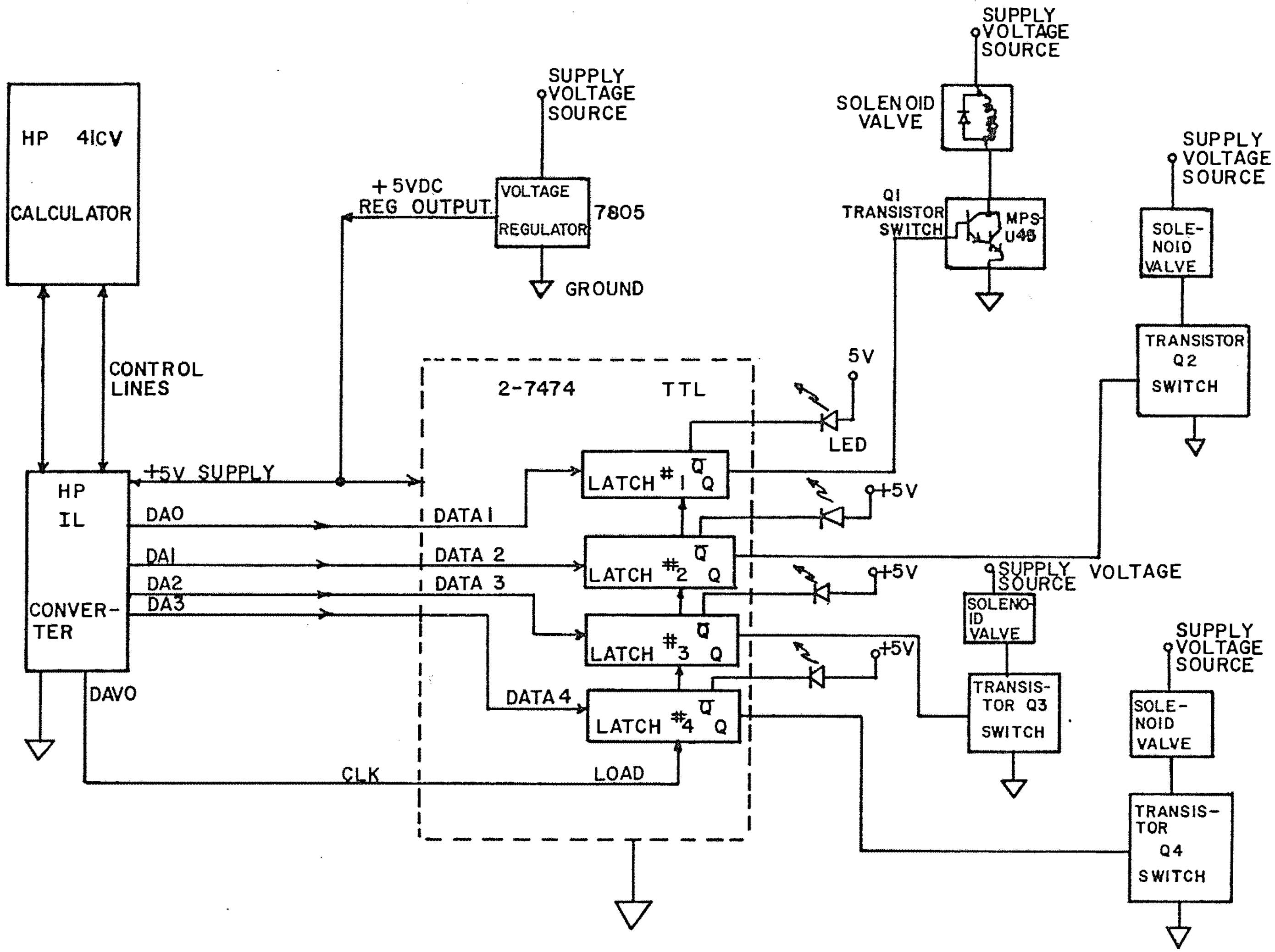


Fig. 6. Schematic drawing of switching unit used to switch valves from Hp IL converter.

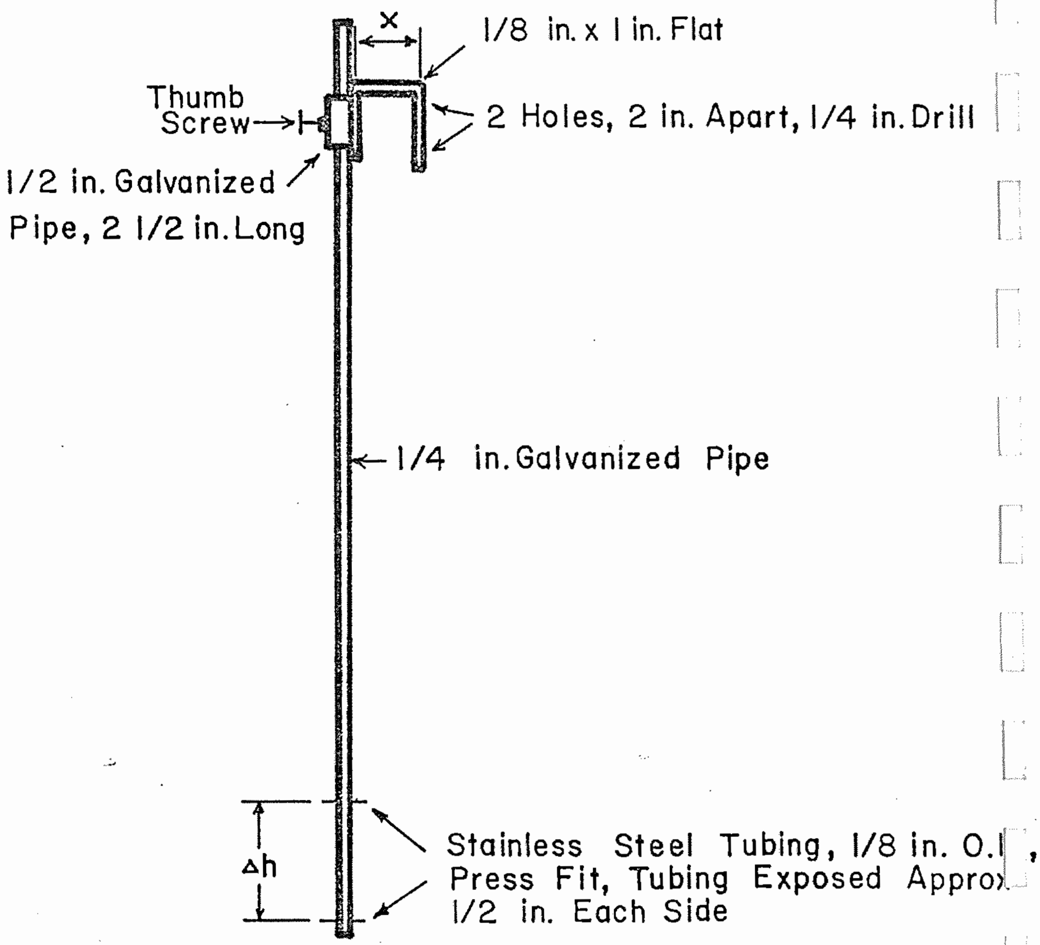


Fig. 7. Schematic of double bubbler and bracket used to attach in stilling well.

TITLE: SURFACE IRRIGATION AUTOMATION

NRP: 20740 CRIS WORK UNIT: 5510-20740-004

INTRODUCTION:

Improved techniques for automating level-basin irrigation systems continue to be sought. Time-based control was originally used on all six automated systems in the Wellton-Mohawk Irrigation and Drainage District (WMIDD). We found, however, that flow fluctuations during an irrigation delivery (time to irrigate entire field of 8 - 23 basins) resulted in ineffectiveness of time-based control (assumes constant flow rate). Furthermore, delivery rates often differ from irrigation to irrigation, which forces the user to change the controller settings even if the volume to be applied is the same as the last irrigation. Thus, conversion from time-based control to flow-rate/volume control has been pursued.

A flow-rate/volume controller for use with surface irrigated systems where the water is delivered in open channels is not available commercially. Our program has dealt mainly with evaluation of depth-detection techniques at flumes, and coupling these to an interface unit built for a specific time-based controller. The controller used is a 12-station microprocessor-based irrigation controller (Model Number CIC-12) manufactured by RainBird Sprinkler Manufacturing Corporation.[1/] The original interface was designed and built by RainBird using a hard wire circuit board and conventional control logic. During 1981 we redesigned the interface to use a microprocessor-based control system in conjunction with a printed circuit board. Development of the microprocessor and evaluation and testing of the microprocessor/analog water depth detection systems were the center of our efforts during 1982. The interface will likely be used only until improved controllers become available commercially. Some maintenance of the automated systems was required and will be briefly described.

VOLUMETRIC CONTROL:

System Components

The basic components required for interfacing with an open channel flow metering device, where flow rate is predictable from a water depth measurement, include a flow depth detecting technique with output proportional to depth and generally a voltage controlled oscillator (VCO). A power

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

function amplifier (discharge related to flow depth by power function) may be required, depending on the capability of the controller used. Volume delivered may be represented by accumulating the flow (integrate) with time or by adjusting the controller delivery time based on flow rate differences from a pre-selected nominal flow. In our work the latter procedure has been developed and features a power function amplifier output being converted to a pulsed output from the VCO. The VCO output (proportional to flow rate) was interfaced with a time-based controller. A schematic of the system components is shown as Fig. 1, in which a bubbler/pressure transducer is used to sense the depth. The distance between the electronics equipment and the flume may be several hundred feet, hence a sensing tube should be used in conjunction with the bubbler air supply tube to avoid head loss problems when operating the bubbler.

The various electronic components include, (Fig. 1): (1) pressure transducer rated at 25 mv span (12v excitation) at 25-in. head; (2) transducer bridge excitation and amplifier module (Mod. 1)--for our system, excitation is regulated at 12 vdc, and the amplified transducer output (V_h) ranges from 0-5 vdc; (3) power module which provides an analog output (V_q) proportional to the input (V_h) raised to a power b (b exponent of $q = ah^b$)--for our case b ranges from about 1.75 to 2.25, depending on the particular flume and V_q, which is proportional to flow rate, ranges from 0-5 vdc; (4) ratio/bias module (Mod. 3) provides precise matching of the output signal from the power module to the VCO; (5) VCO module which delivers a square-wave output (0 and 5v) with frequency proportional to flow rate; (6) microprocessor-based interface which operates in response to the pulse rate--in our system 1 pulse/min. is proportional to some preselected nominal flow rate, with adjustments in controller station run time increased or decreased, dependent on the pulse rate differing from nominal; and (7) irrigation controller.

<u>Analog to VCO Performance - An Example</u>

We have had some problems with the Action equipment that resulted from faulty parts in the original purchase, but these have been corrected. An example of how the transducer-to-VCO output performed is illustrated in Table 1. The system was checked at three flow depths equivalent to 13.[illegible]0, 21.07, and 27.30 cfs for an FB1 type flume. The power function describing the flow vs. head of an FB1 flume is $q = 15.8117h^{1.7799}$, and nominal flow in the example was 20 cfs. The adjusted flow rates (q_a), calculated from the VCO pulse rate output, were less than actual by as much as 2.3%. Fine tuning the calibration of the system likely could reduce the error. The exponent from the power module conversion of V_h to V_q was 1.7723, compared to 1.7799 required.

Microprocessor-Based Volumetric Interface

The primary function of the interface unit is to interact with the RainBird time-based controller (CIC-12) and adjust the displayed time in proportion to flow-rate. The adjustment is made relative to a user-selected nominal flow rate. At nominal flow (q_n) the pulse rate from the VCO is one pulse/min. (t_n). The volumetric interface equipment is physically mounted inside the CIC enclosure directly on the back of the CIC printed circuit board. A schematic of the volumetric interface is shown as Fig. 2. Procedures for adding the volumetric board to the RainBird controller and necessary modifications follow:

(1) Remove the CIC circuit board from the faceplate. Add jumper wire from 'E2' solder run of Q14 to J3 pin 9 on the CIC.

(2) Jumper J3 pin 8 to voltage regulator Q15 pin 3 on the CIC.

(3) Jumper pin 1 of J3 to pin 28 of U15 on the CIC. Install a 16 pin DIP socket to position marked J3 on the component side of the RainBird circuit board.

(4) Cut the solder run leading to J3 pin 16 on the CIC.

(5) Drill a hole on the CIC faceplate and mount SW1 SPST switch. Connect an 8 in. pair of wires from the switch to a Molex plug J2, shown in Fig. 2 as HRS/MIN input.

(6) Drill a hole and install a LED in the faceplate of the CIC to indicate volumetric operation. Connect an 8 in. pair of wires from the LED to J2 as shown in Fig. 2.

(7) Remove the 9 vdc rechargeable battery from the CIC; replace battery clip and leads with a one-ft-long set of leads using the same style battery clip; and replace the square 9 vdc NI CAD battery with a battery pack containing six 1.2 vdc NI CAD penlight batteries.

(8) Remove the four screws that hold the keyboard standoffs in the center of the RainBird circuit board, and replace with screw-in type 1-inch standoffs. Mount the volumetric board on the 4 standoffs just added and reconnect the faceplate to the CIC circuit board.

(9) Connect a wire from the CIC capacitor C18 positive side to the volumetric interface board voltage regulator pin 1.

(10) Connect a 16 pin DIP to 16 pin DIP ribbon cable from J3 on the CIC to J3 on the volumetric board.

(11) Remove the set of blue wires from the CIC transformer inside the enclosure going to the screw terminal marked BLUE and replace with a 14 vac transformer located outside the enclosure. Connect the 14 vac transformer output leads to the terminals marked BLUE.

Volumetric Circuit Operation and Chip Functions, Fig. 2

STANDBY MODE: When the CIC is turned on, it will show the time of day. The volumetric LED will be off.

SWITCH SW1: The CIC can operate either in an HOUR or MINUTE mode (99 min or 9.9 h maximum). SW1 sets the volumetric microprocessor into either the HOUR or MINUTE mode.

HRS/MIN LINE: This line is read by the volumetric microprocessor only when the volumetric interface is first activated or powered up. This line, depending on how switch SW1 is set, will read either zero or - vdc. Zero voltage indicates the MINUTE MODE of operation. The program HOUR or MINUTE modes result in the setting of the internal timer on board the volumetric microprocessor. Any SW1 switch setting change after initial startup will be ignored until the volumetric microprocessor is disengaged from operation.

START: The CIC controller can be started either by depressing the MANUAL START key on the CIC or by the volumetric microprocessor via an off-board remote start relay. When a circuit activation is effected by the remote start relay, the volumetric microprocessor signals the CIC to start via the MONITOR and MANUAL START keys. When the CIC initiates a start, the Master Value line (Pin 9 J3) goes low, which signals the microprocessor to start. The remote start input line is diode-protected (D1 and D2) from spurious spikes that could cause false starts.

WAKE-UP CIRCUIT: The wake-up circuit is to hold the volumetric microprocessor MONITOR and START key lines low (disabled) during power-up of the microprocessor and volumetric board. This eliminates false starts when power is applied. When full voltage is reached, the wake-up circuit releases the two lines back to the volumetric microprocessor. The wake-up circuit that contains the 74C14 IC chip is powered by the CIC power supply since the CIC microprocessor has a battery backup to retain programmed memory in case of power failure. Very little power is used since the IC used in the wake-up circuit is CMOS.

PULSE INPUT: The pulse rate is proportional to flow rate. Adjustments to the time left to run on the CIC are made in reference to nominal flow. The pulse rate at nominal flow is 1 pulse/min. Time on the CIC is incremented or decremented by the microprocessor via the UP or DOWN key transistors and the MONITOR key transistor on the volumetric board. TIME to completion for a particular channel will be either shortened (fast pulse rate, flow above nominal, more DOWN key than UP key signals from microprocessor) or lengthened (slow pulse rate, flow rate below nominal, more UP key than DOWN key signals). The system will default to standard time-based operation if a pulse is not received in 5 min. (MINUTE mode of operation) and 0.5 h (HOUR mode). A LED light was added to the face of the CIC to indicate volumetric interface operation and that the pulse input is being checked. The LED is turned on whenever the microprocessor is running the internal program.

UP, DOWN, MONITOR AND START KEY CONTROLS: When the volumetric microprocessor performs an up or down count or start to the CIC, the microprocessor sends a monitor pulse and a corresponding up or down count or start pulse from port 2 of the volumetric microprocessor. The corresponding buffer amplifier on the line being pulsed receives the output pulse from the volumetric microprocessor and drives the respective transistors (Q1 through Q4). The transistors effect is as though a key had been pressed on the CIC keypad. The transistors are connected to the RainBird via a ribbon cable and a 16 pin DIP connector. Each pulse out of the volumetric microprocessor is about 32 milliseconds.

DAISY CHAIN RELAY: This device provides the signal for remote starting additional CIC units when more than the 12 operation channels are needed. Prior to going to the STANDBY mode, the volumetric microprocessor will close the daisy chain relay and effect an off board remote start. The relay is internally diode-protected to eliminate current and voltage spikes that may be induced back into the microprocessor.

OTHER MISCELLANEOUS ITEMS:

7805 VOLTAGE REGULATOR - Supplies +5 vdc to all active components on the volumetric board except the wake-up circuit 74C14 IC.

IC BUFFERS - These are driver buffers for the microprocessor input and output lines.

CRYSTAL AND ASSOCIATED CAPACITORS (C1 and C2) - These are associated with the oscillator circuit for the volumetric microprocessor.

RESET CAPACITOR C3 - This provides an internal pulse in the volumetric microprocessor when a power outage occurs and power is returned. The resetting starts the microprocessor again as if it has just begun operation, even if the microprocessor was interrupted during a normal operation period.

J3 CONNECTOR - This 16 pin DIP socket connects the volumetric microprocessor control signals to the CIC unit.

J2 CONNECTOR - This connects the volumetric board to the REMOTE START RELAY, VOLUMETRIC PULSE INPUT, GROUND, AND POWER LINES.

J1 CONNECTOR - This connects the HRS/MIN switch and VOLUMETRIC LED signals to the volumetric board.

PULSE LED - LED indicates that a pulse is present and can be used to check pulse rate.

Interface Performance

Performance of the interface system was tested extensively during 1982. Tests were conducted by removing the excitation/amplifier module and inputting to the power module a regulated voltage simulating V_h of Fig. 1. This assured a steady pulse rate. The system was tested in both the MINUTE and HOUR modes of operation. In the MINUTE tests the controller was programmed with 60 min. in each of 9 stations. Pulse rates were held constant for each test at 0.80, 1.05, and 1.32 pulse/min., where nominal is 1 pulse/min. These pulse rates correspond to adjusted station times of 75.0, 57.1, and 45.6 min. respectively. For the HOUR tests controller station time settings were different from test to test (1.0, 2.0, 3.0, and 4.0 h for each of 9 or 10 stations) but the pulse rate was essentially constant for all tests (0.79 or 0.80 pulse/min).

Statistics for the two data sets are presented in Tables 2 and 3. The average station time for a test ($\overline{t_m}$) was within one digit of what the time should have been (t_c) whether in MINUTE or HOUR mode (1.0 min. and 0.1 h, respectively), which is as accurate as the algorithm can be. The most concerning aspects, however, arise when the individual station deviations (Δt) are inspected. Here we find that maximum deviations in the MINUTE mode are as high as 4.0 min., which for the particular test represents an error of 5-6% (Table 2). The corresponding values in the HOUR mode go as high as 0.47 h for the 3.0 h test, representing a deviation from expected of 12.5% (Table 3). These deviations are greater than allowable. Original accuracy criteria for the interface algorithm was to be within one controller digit for all stations (1 min. for MIN mode and 0.1 h for HOUR mode). Maximum error would range from about 10 to 1% in the MINUTE mode (10-99 min. station settings). The corresponding error in the HOUR mode would range from 6.2% (at the transition from MINUTE to HOUR mode of 1.6 h or 96 min.) to 1% at a 9.9 h setting. Hence, it is apparent that the algorithm function must be improved to meet the original accuracy criteria. Such an improvement will be considered during 1983.

ON-FARM AUTOMATED SYSTEMS:

Preparations were made during 1981 to convert four of the original time based automated systems in the WMIDD to volumetric control. All field changes necessary to effect such a conversion were made during 1981 and early 1982, which included either additional air/electrical installation or control center changes. Unforeseen problems with the newly designed microprocessor based volumetric interface unit delayed volumetric use of the converted systems. The interface system was tried and tested many times in the field during the year. As problems arose, modifications were made, which have resulted in the system described earlier and illustrated schematically in Fig. 2. Modifications have centered around circuit isolation, power supply improvement, and provision for field monitoring capability. We are reasonably certain that the modified interface system presented in Fig. 2 will function satisfactorily in the future. Final modifications will be made to all systems in early 1983, to be followed by field installation and use during the 1983 irrigation season.

Woodhouse System

The volumetric control equipment was tested extensively on the Woodhouse system with the results used as a basis for many of the system modifications. Two irrigations were completed on the Woodhouse farm using the volumetric control. An irrigation on 8 July 1982 is summarized in Table 4. A 4.75 in. irrigation was scheduled which resulted in controller time settings (t_s) of 2.3 to 4.3 h at a nominal flow of 16.27 cfs. Flow varied during the irrigation from 15.5 to 17.5 cfs. Three of the six stations were within one controller digit (0.1 h) of the correct time (t_c). The average error was 4.6% while the average flow fluctuation from nominal was only 3.8%, hence the volumetric adjustment was inadequate for the reasons discussed in the previous section.

All automated gates continued to function satisfactorily without repair or change. Equipment used at the gates is the original, installed in 1975.

Naquin System

The microprocessor based volumetric interface system was tested several times during the year on the Naquin Farm. Again, some of the problems with the equipment were found while testing at this site. The system was used without the volumetric interface a number of times in 1982.

In one instance, copper tubing corroded when in contact with the soil. The copper tubing will be replaced with gopher protected polyethylene tubing.

McElhaney-McDonnell System #1

A new control center, featuring the RainBird controllers and interface equipment for volumetric control, was installed during 1982, Fig. 3. The original, pneumatic operated, control center was modified by converting the 26.5 vac controller output signal to a pneumatic signal by solenoid operated three-way valves. In this way gate signalling is still done pneumatically, and no changes were needed outside the control center. Control center conversion took about 15 manhours (7.5 h, 2 people). Two controllers were daisy-chained together to provide control to 23 fields (12 maximum per controller) -- function described earlier. Water rundown (electromechanical relays), manual override, and random sequencing (matrix board) were provided. The analog/VCO link between a pressure transducer sensor and the volumetric interface will not be installed until we are sure all equipment is operating satisfactorily. A pulse generator has been added to provide a constant pulse rate of 1 pulse/min. which will allow time-based operation.

The automated system, originally installed in 1977, had not been used by the farmer since leasing the land to another operator in 1981. Only a few items needed maintenance when the system was checked in the fall of 1982. The reasons for needing maintenance included (1) Polyethylene (PE) tubing UV degradation--one instance when tubing exposed at check gate, (2) Mechanical--one instance where tube pulled out of connector, (3) Gopher damage--one instance at overflow where PE tubing was inadvertently unprotected, and (4) Burning--two instances where PE tubing had been melted when the ditch banks were burnt by the farmer. The burning is a common practice in the area but has caused problems before. The system functioned satisfactorily after the maintenance was completed. Maintenance time was about 11 h (5.5 h, two people). The system will b used during 1983.

Joe Hoffman System #1

The system was hooked up to AC power during 1982. The system was checked electrically and pneumatically and found to function satisfactorily. Th volumetric controller was not used during 1982. All required interface modifications will be made and the system will be readied for use in 1983.

Hoffman Enterprises System #1

The system was hooked up to AC power early in 1982 which required some rewiring at two gates. Electrical wires and PE tubing were damaged extensively by gophers. In all cases, the damage was where the wire or tubing was not inside the concrete, at locations where hand plastering had been done. This is one of the systems in which the wire and tubing were encased in the concrete at the time of slipforming in 1978. Since we were still interested in the utility of concrete encasement, the system was rehabilitated by splicing and protecting the damaged areas. After rehabilitation, the the system functioned properly both electrically an pneumatically.

The system was used to irrigate three times during 1982. An irrigation was started in June using the volumetric interface, but it malfunctioned. The irrigation and any subsequent irrigations were completed using time-based control. Appropriate updating of the volumetric interface is planned.

McElhaney-McDonnel System #2

Gophers destroyed the insulation on the buried electrical power line, which led to failure when corroded later. Overhead electrical power was restored to the system in April. Gophers also chewed PE tubing where i was inadvertently unprotected. All damage areas were repaired. The volumetric system--the first developed, used a hard wire circuit board and conventional control logic--continued to function when used during the year. The flow depth sensing at the flume is done using a capacitance system. Calibration stability of the interface unit will be evaluated in 1983. The system was installed in the fall of 1980.

General

The commercially purchased float-microswitch system used to signal excessive water depth in the canals (overflow) was modified to provide more positive action of the microswitch. This involved a larger float, added weight to the float, and adjustment of the holding bracket to accommodate the larger float. The modified versions were added to the Naquin and Hoffman systems in 1982.

Although we have experienced a considerable amount of electronic interface problems associated with the conversion to volumetric control, the interface between the operator and controller may be even more of a problem. The introduction of electronic devices such as these tends to be somewhat confusing to users and can become a deterrent to full use. We are planning to construct a practice control center that can be left with the users, as needed. More time will be spent explaining the operation of the units, and improved instructions will be developed. Much of the problem centers around infrequent use of such systems--irrigate only once or twice a month.

Four private companies, interested in developing and marketing flow monitoring and automation system packages, have contacted us here in Phoenix. Our involvement has ranged from blackboard discussions regarding design requirements of monitoring, control, and gate modification, to visits to the Wellton-Mohawk Irrigation and Drainage District to study the on-farm systems firsthand. One company is planning a prototype automation system installation in cooperation with a farm in the WMIDD during 1983. Much of the gate modification and control logic is patterned after our work.

SUMMARY AND CONCLUSIONS:

Development of a microprocessor-based interface for adapting a normally time-based controller (assume constant flow rate) to a flow rate controlled system was pursued. The interface provides the link between commercially available analog equipment used to detect water depth with either bubbler/pressure transducer or capacitance type systems and a commercially available time-based controller. A flow rate controlled system is needed for the six operational automated systems in the Wellton-Mohawk Irrigation and Drainage District, but none are available commercially. We anticipate using the adapted systems only until improved controllers become available.

Gophers and ditch bank burning by the farmers continue to be the main problems with equipment in the field, and are mainly associated with the power linkage to the gates--electrical wire for signals and polyethylene tubes for the air supply. Gopher problems have occurred, however, only when the wire and tubing were not properly encased, either in concrete or PVC pipe. Function of the gate modification equipment has been outstanding with that originally installed in 1975 still operating.

Four private companies, interested in developing flow monitoring and automation system packages, contacted us here at Phoenix. One company is planning a prototype automation system installation during 1983.

PERSONNEL: A. R. Dedrick

Table 1. Performance of analog to VCO equipment used to signal microprocessor-based interface to adapt time-based controller to flow rate-based control. Test was conducted after modules have been calibrated for use on JH #1 automated system.

	Output Voltage				Flow Rate		
Flow Depth h	Mod 1 V_h	Mod 2 V_q 1/	Mod 3 V_q 1	Pulse Rate t	Actual q 2/	Adjusted q_a 3/	Er[illegible]r
(ft)	(vdc)	(vdc)	(vdc)	(sec)	(cfs)	(cfs)	([illegible])
0.930	2.246	1.204	0.316	86.8	13.90	13.82	-0.5
1.175	2.824	1.806	0.486	57.5	21.07	20.87	-[illegible].0
1.359	3.266	2.338	0.636	45.0	27.30	26.67	-2.3

1/ $V_q = 0.287\ V_h^{1.7723}$ (Curve Fit of V_h vs V_q)

2/ $q = 15.8117h^{1.7799}$ (curve fit for FB1 Flume $10\text{ cfs} \leq q \leq 26\text{ cfs}$)

3/ $q_a = \frac{60}{t} q_n$ where q_n = nominal flow rate = 20 cfs

Table 2. Statistical analyses of volumetric interface performance when operating in MINUTE mode.

Controller Time Setting (min.)	60		60		60	
Pulse Rate from Mod 4 (pulse/min.)	0.80		1.05		1.32	
Calculated Station Time, t_c (min.)	75.0		57.1		45.6	
Controller Station	t_m 1/	Δt 2/	t_m	Δt	t_m	Δt
			(min.)			
1	72.0	-3.0	57.0	-0.1	43.0	-2.6
2	79.0	4.0	58.0	0.9	47.0	1.4
3	75.2	0.2	60.8	3.7	46.8	1.2
4	74.6	-0.4	57.0	-0.1	45.9	0.3
5	78.0	3.0	60.0	2.9	45.0	-0.6
6	74.0	-1.0	57.0	-0.1	47.8	2.2
7	78.0	3.0	56.0	-1.1	44.0	-1.6
8	74.6	-0.4	56.6	-0.5	45.0	-0.6
9	78.8	3.8	60.8	3.7	44.8	-0.8
$\overline{tm}$ (min)	76.0	1.0	58.1	1.0	45.5	-0.1
s_t (min)	2.5		1.9		1.5	
CV (%)	3.3		3.3		3.3	
d_m 3/ (min)	4.0		3.7		2.6	
(%)	5.3		6.5		5.7	

1/ Time each controller station actually ran.
2/ $\Delta t = t_m - t_c$.
3/ Maximum station deviation from t_c.

Table 3. Statistical analyses of volumetric interface performance when operating in HOUR mode.

Time Setting (h)	1.0		2.0		3.0		4.0	
Pulse Rate from Mod 4 (pulse/min.)	0.79		0.79		0.80		0.79	
Calculated Station Time, t_c (h)	1.26		2.53		3.77		5.03	
Controller Station	t_m 1/	Δt 2/	t_m	Δt	t_m	Δt	t_m	Δt
	(h)							
1	1.10	.16	2.40	-0.13	3.78	0.01	5.17	0.14
2	1.20	- .06	2.50	- .03	3.80	.03	4.90	-.13
3	1.20	- .06	2.68	.15	.30	- .47	5.30	.27
4	1.20	- .06	2.40	- .13	4.08	.31	5.20	.17
5	1.31	.05	2.78	.25	3.80	.03	4.90	-.13
6	1.40	.14	2.68	.15	3.62	- .15	5.25	.22
7	1.40	.14	2.80	.27	3.90	.13	5.12	.09
8	1.40	.14	2.60	.07	3.58	- .19	5.18	.15
9	1.30	.04	2.40	- .13	3.40	- .37	5.00	-.03
10	1.30	.04	2.62	.09			5.28	.25
$\bar{t}_m$ (h)	1.28	0.02	2.59	0.06	3.70	-0.07	5.13	0.10
s_t (h)	0.10		0.15		0.25		0.15	
CV (%)	7.8		5.8		6.8		2.9	
d_m 3/ (h)	0.16		0.27		0.47		0.27	
(%)	12.7		9.9		12.5		5.0	

1/ Time each controller station actually ran.
2/ $\Delta t = t_m - t_c$.
3/ Maximum station deviation from t_c.

Table 4. Performance of volumetric control equipment during an irrigation on the Woodhouse Farm, 8 July 1982. At nominal flow (16.27 cfs), the power module voltage was 1.39.

Controller Station	Power Module Voltage Ratio1/	Controller Station Time				
		t_s2/	t_c3/	t_m4/	Δt5/	Error
		(hr)				(%)
1	1.04	2.5	2.60	2.33	-0.27	-10.4
2	1.02	2.3	2.35	2.30	- .05	- 2.3
3	0.95	2.3	2.17	2.20	.03	1.4
4	0.93	2.3	2.13	2.20	.07	3.3
5	1.00	3.0	3.00	2.80	- .20	- 6.7
6	1.05	4.3	4.52	4.68	.16	3.5

1/ Ratio of voltage from Power Module at nominal flow (V_{qn}) to voltage from Power Module (V_q) monitored during irrigation--V_{qn}/V_q.
2/ Controller time setting.
3/ Time controller should run per station--$(V_{qn}/V_q)t_s$.
4/ Actual time irrigated.
5/ $\Delta t = t_c - t_m$.

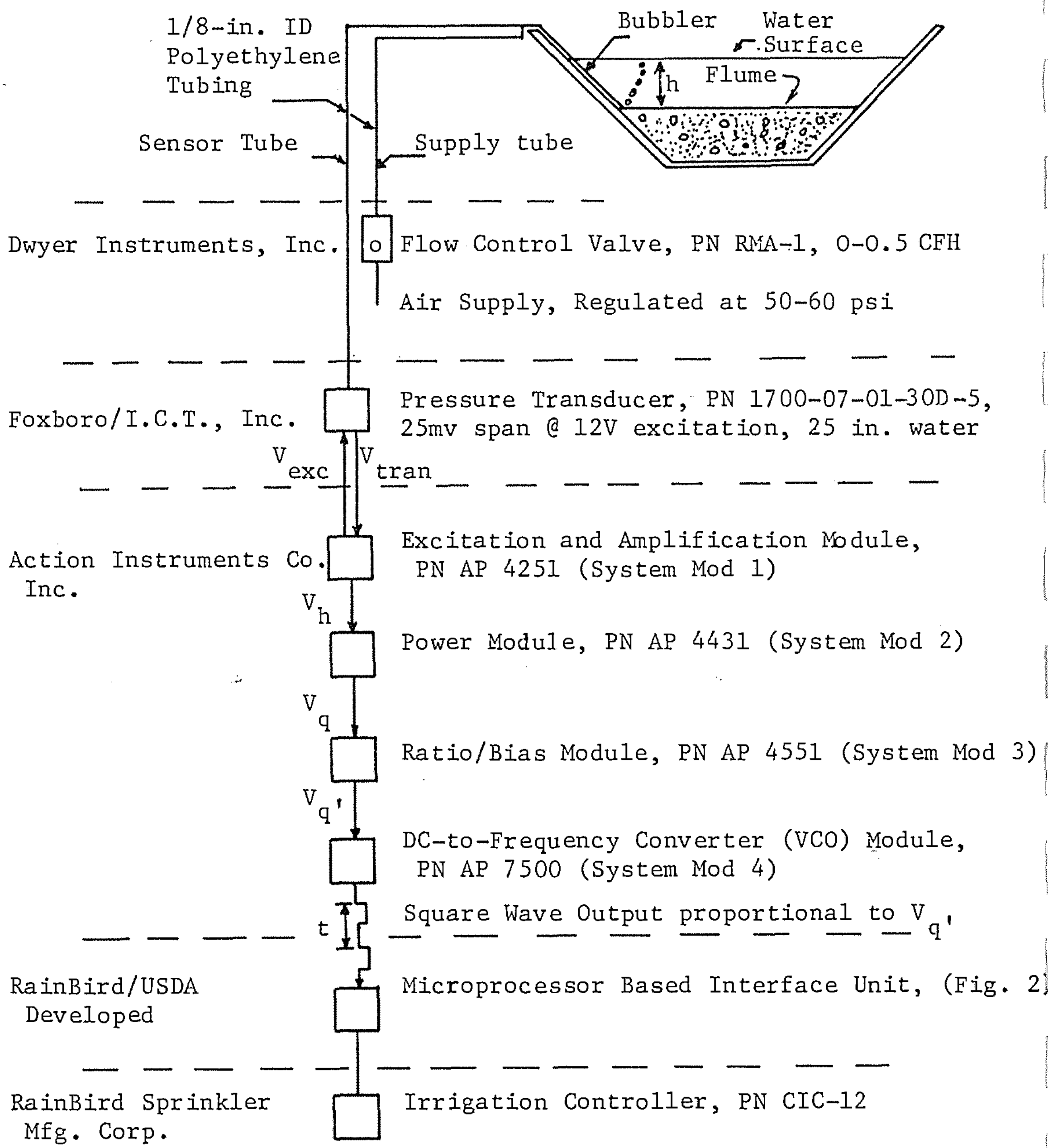


Fig. 1. Schematic of water depth sensing technique along with analog and microprocessor based equipment used to effect conversion of the conventional time-based controller to a flow-rate controlled system.

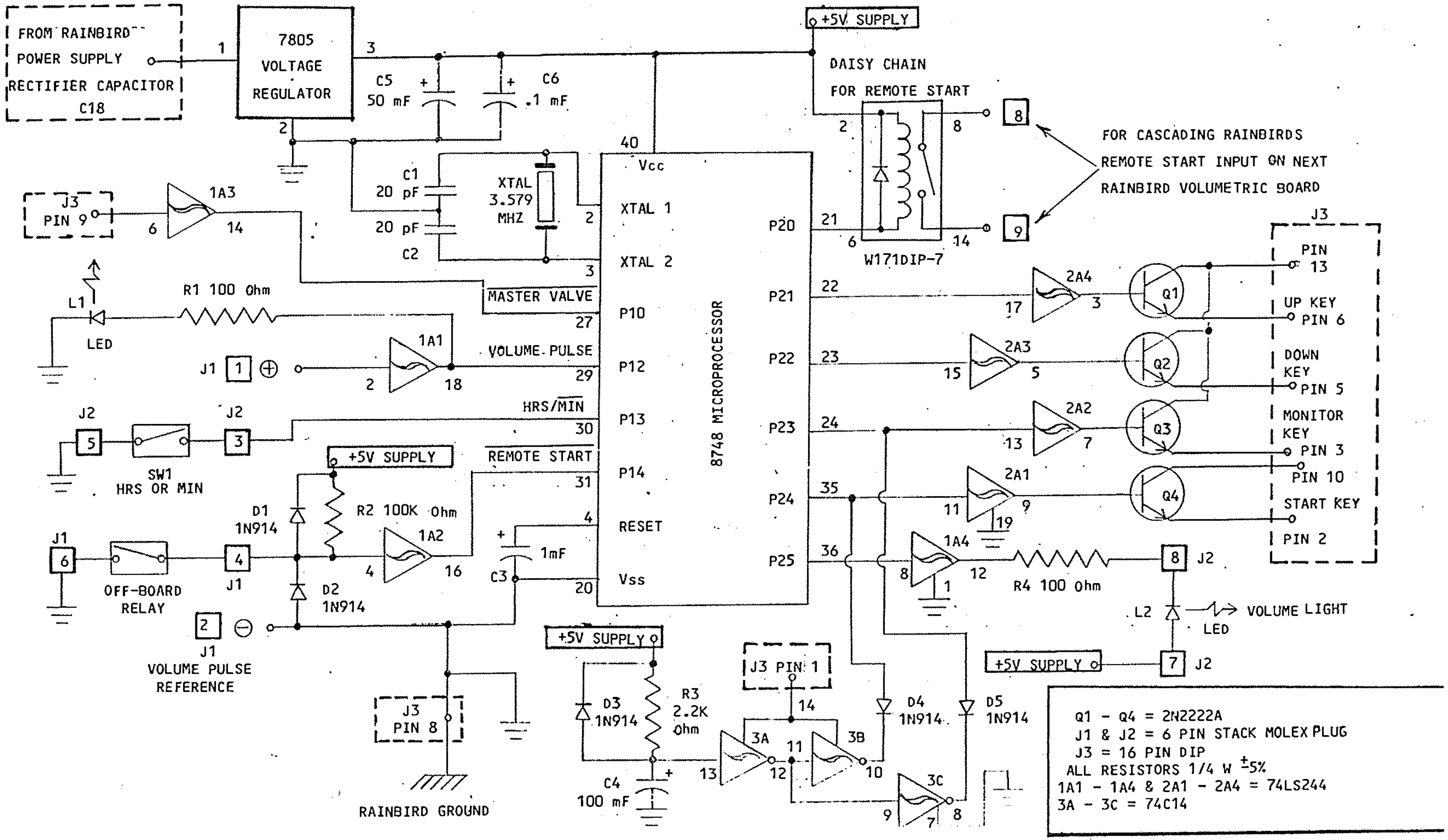
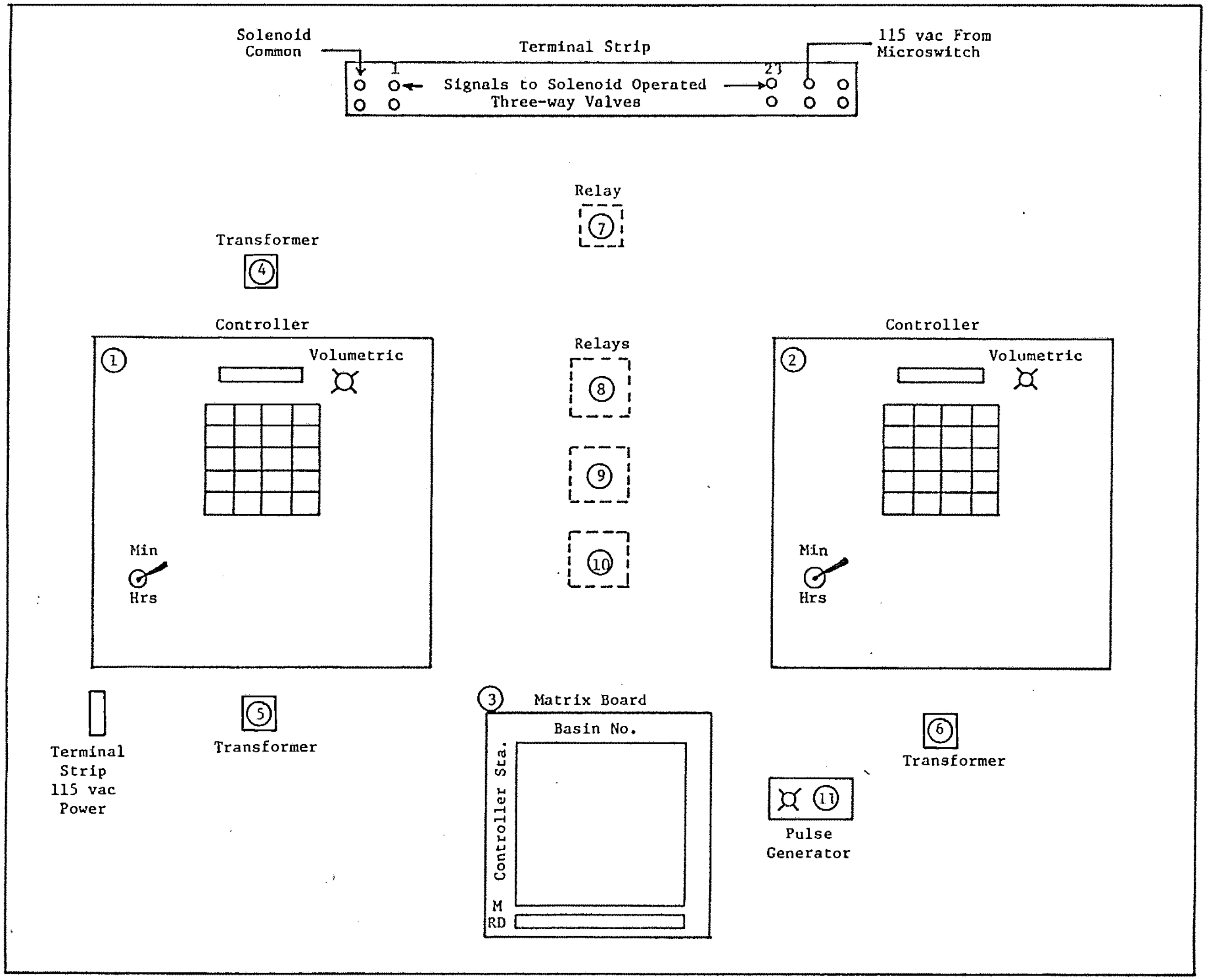


Fig. 2. Microprocessor-based interface developed to operate RainBird Irrigation Controller CIC-12 as a flow-rate rather than time-rate controlled device.



ITEM(S)	DESCRIPTION/ EXPLANATION
1 & 2	Controllers: 12 Station, (PN CIC-12) daisy chained together.
3	Matrix Board: provide random sequencing, manual operation (M), and rundown selection (RD).
4	Transformer: 24 vac to power manual (M) and rundown (RD) from matrix board.
5 & 6	Transformers: 15 vac to power microprocessor in controllers (both CIC-12 and volumetric interface microprocessors).
7	Relay: SPDT, 115 vac signalled by overflow operated microswitch to create autostart signal (relay closure) to controller.
8,9,10	Relays: 4PDT, 24 vac signalled by Station 12 of Controller 2 to provide rundown function. Relay signalling closes circuits between transformer 4 and basins selected for Rundown (Pinned on Matrix Board).
11	Pulse Generator: Simulation of nominal flow (temporary), 1 pulse/min.

Fig. 3. Schematic diagram of control center installed in 1982 on McElhaney-McDonnell System #1. RainBird controllers and interface equipment for volumetric control are featured along with matrix board for random sequencing and relays used to provide autostart and rundown functions.

TITLE: WATER AND AGRONOMIC MANAGEMENT FOR ECONOMICAL GUAYULE RUBBER PRODUCTION UNDER DIFFERENT CLIMATIC AND SOIL CONDITIONS

NRP: 20740 CRIS WORK UNIT: 5510-20740-012

INTRODUCTION:

A brief review of literature and a need for water and agronomic management research on guayule was presented in the 1981 Annual Report. The three main objectives of this comprehensive study are as follows:

(1) Determine water requirements, evapotranspiration (ET) estimates, and irrigation scheduling techniques for maximizing guayule rubber and resin production on a unit water and economic basis.

(2) Determine guayule irrigation and minimum and maximum fertility requirements on marginal agricultural land with limited surface and groundwater supplies.

(3) Determine basic plant physiological and environmental factors that can be related to growth, water stress, and rubber synthesis in guayule.

Guayule cultivars 11591, N565-II, and 593 were planted at three locations in replicated, large field plots to evaluate climatic and soil variables that affect yield and irrigation water management. Soil variables include a medium-textured, medium water-holding capacity (Mesa, Arizona); a heavy-textured, high water-holding capacity (Brawley, California); and a coarse-textured, low water-holding capacity (Yuma, Arizona). The Mesa location was planted in the spring of 1981; the Brawley location was replanted in the fall of 1981; and the Yuma location was planted in early 1982. A combination water-fertility study is being conducted at Yuma, and bioregulators are also being evaluated in respect to rubber yields and drought tolerance at Mesa and Yuma.

Mesa, Arizona

Field Procedures:

On April 7-9, 1981, the three guayule cultivars were hand transplanted at the Mesa Experiment Farm, University of Arizona, in a randomized block design. Figure 1 shows the field layout, along with irrigation, cultivar, and bioregulator treatments. Two rows were planted on raised beds approximately 1 m on center with a 36-cm (14-in.) spacing between plants along the row for a population of 54,000 plants/ha. About one-sixth of each plot includes transplants that were treated twice in the greenhouse with two types of bioregulators, followed by field sprayings at two-month intervals after transplanting except for winter months. The bioregulator compounds were 2-diethylaminoethyl 1-3, 4-dichlorophenylether and 2-diethylaminoethyl 1-2, 4-dichlorophenylether.

Starting on January 1, 1982, after eight month's growth, the following six irrigation treatments were used: (I_1) irrigate when 60% of the available soil water has been depleted; (I_2) irrigate when 80% of the available soil water has been depleted; (I_3) irrigate when 90% of the available soil water has been depleted; (I_4) irrigate when 90% of the available soil water has been depleted, plus a two-week delay; (I_5) irrigate when 90% of the available soil water has been depleted, plus a four-week delay; and (I_6) irrigate three times per year. The 0-180-cm (6-ft) soil depth was used to schedule irrigations and calculate soil water depletions in 1982. Volumetric water contents were determined by neutron moisture meters with 36 neutron access tubes located in replicates 2 and 3 on all three cultivars, and six irrigation treatments to a 3-m (10-ft) soil depth. On the medium water-holding capacity Laveen loam soil, field capacity has consistently been estimated at 25.7% by volume, whereas a wilting point of 8.6% was estimated from recurring lower limits of water uptake on older guayule plants.

Water applications at each irrigation were measured by a propeller-type water meter, and aluminum gated pipe was used in delivering water to the individual plots surrounded by earth border dikes covered with plastic film. Meteorological factors affecting ET were monitored beginning in August 1981, by portable stations equipped with CR 21 microloggers. Weather data were determined on the I_2 irrigation treatment for guayule and on an adjacent alfalfa field for a reference crop. On the guayule wind speed was determined at the 2-m (6.6-ft) height; net radiation, air temperature, and relative humidity at the 1.5-m (4.9-ft) height; net radiation initially at 1/2 the plant height; and soil temperature at the 1-cm (0.8-in.) depth. On the alfalfa, solar radiation and wind speed were determined at the 2-m (6.6 ft) height; net radiation, air temperature, and relative humidity at the 1.5-m (4.9-ft) height; and soil temperature at the 1-cm (0.8 in.) depth.

Beginning in October 1981, infrared thermometers were used to remotely monitor guayule plant temperatures and estimate plant stress. Plant temperatures were taken on six untreated and six bioregulated plants for each of the three guayule cultivars and six irrigation treatments in replicates 2 and 3. Vapor pressure deficit was determined 1 m above the crop with a portable psychrometer before and after taking infrared thermometer readings. Plant-air temperature differences versus atmospheric water vapor pressure deficit under well-watered conditions were used to develop the crop stress baseline following the method of Idso et al. (1981) for other crop types. Crop water stress indices for guayule were computed from the plant, air temperatures, and vapor pressure deficits.

Leaf area, plant size, plant weights, and rubber and resin contents were also being sampled at least four to five times per year beginning in August 1981. Two plants per cultivar and irrigation plot were selected for each harvest date, as described in Figure 2, for a total of 144 whole plants. In addition, each plant was divided into upper branches (above a 10-cm plant height), lower branches (soil surface to a 10-cm plant height), and roots (soil surface to a 12-15-cm depth). The fina harvest date is presently being planned for the fall of 1984, with at least 36 plants to be harvested per cultivar and irrigation plot.

Results and Discussion:

As discussed in the 1981 Annual Report, better than 95% transplant survival was obtained by careful control of water applications with a sprinkler irrigation system for all three cultivars. The seasonal water depletions (ET estimates) for the six irrigation treatments in decreasing order of water applications were: 955, 780, 705, 600, 605, and 605 mm (37.6, 30.7, 27.8, 23.6, 23.8, and 23.8 in.) from May through December 1981. Plant growth decreased significantly among the three wetter treatments, while little difference was noted on the three drier treatments. Soil water content profiles also indicated that guayule roots extracted water to depths greater than 140 cm by the end of the first season, regardless of the amount of water applied or irrigation schedule.

Table 1 lists the amounts of water applied on the six irrigation treatments in 1982. Water application ranged from 2021 mm (79.6 in.) with twelve irrigations on the I_1 treatment to 500 mm (19.7 in.) with three irrigations on the I_6 treatment. Annual precipitation totaled 256 mm (10.0 in.) on all plots. Plant heights decreased consistently with reduced irrigation amounts for the I_1 through I_6 treatments for all three cultivars as shown in Figure 3. Cultivar 11591 is taller than cv. N565-II, followed by cv. 593 for the I_1 through I_4 treatments; and cv. 11591 and N565-II are nearly the same height in I_5 and I_6 treatments, with both being taller than cv. 593. In respect to bioregulated versus untreated guayule plants, the bioregulated plants tend to be taller than the untreated ones in all irrigation treatments except for the I_6 treatment, where the opposite trend was measured (Figure 4).

Changes in the soil water content averaged for the three cultivars versus time showed that irrigations were actually applied when 69, 82, 88, 90, 87, and 90% of the available soil water was depleted in the 0-180-cm soil depth for the six irrigation treatments, respectively (Figures 5-10). The reduced growth and shedding of plant leaves on the I_4, I_5, and I_6 treatments in the summer of 1982 possibly limited the ability of the guayule plants to extract water below the 90% level. Figures 11-16 present soil water content profiles through a 3-m soil depth and estimated plant rooting depths for selected dates on the six irrigation treatments. By the fall of 1982, plant roots had penetrated to an estimated depth of 180 cm (6 ft), which compares with the 140-cm (4.6-ft) depth at the end of 1981, regardless of the irrigation treatment. These figures also indicated that guayule removed soil water below the present wilting point (8.6% by volume) to a depth of about 120-cm (4 ft).

Average soil water depletion rates (estimates ET) for the three cultivars and six irrigation treatments are shown in Figures 17-22. The estimated seasonal water used for each irrigation treatment in order of decreasing water applications was 2050 mm (80.7 in.), 1630 mm (64.2 in.), 1340 mm (52.8 in.), 1125 mm (44.3 in..), 870 mm (34.3 in.), and

920 mm (36.2 in.), respectively. These depletion rates were consistent with plant height measurements which showed major differences in growth on the four wet and medium treatments and little difference in growth on the two dry treatments. In comparing the seasonal soil water depletion with the total water applied (irrigation amounts plus precipitation), water application efficiencies in 1982 ranged from 90, 93, 106, 102, 107, and 120% for the six irrigation treatments, respectively. The application efficiencies of higher than 100% represent the stored moisture from 1981 that was used in 1982. A trend of increased soil water depletion for the cv. 11591 over N565-II over 593 was demonstrated on the two wet (I_1 and I_2) treatments, but consistent differences were not measured on the medium and dry (I_3, I_4, I_5, and I_6) treatments. Also, soil water depletion rates tended to decrease between early June to mid-July for a three to four-week period for the wet and medium (I_1, I_2, I_3, and I_4) treatments, but this trend was not evident on the dry (I_5 and I_6) treatments. Possible reasons for the reduced depletion rate during the summer are decreased flowering or seed production and/or reduced leaf area (dropping of plant leaves) during high temperature periods. On the dry (I_5 and I_6) treatments, flowering was earlier than the other treatments and lasted from early March through mid-April, with seeds dropping to the ground by early May.

Plant harvests were made in the middle of the month for August and December 1981, followed by February, May, July, and September 1982. Crown diameter (diameter at the soil surface), aboveground harvested plant volume, leaf area index, and total dry matter for the first four harvest dates of the six irrigation treatments and three cultivars are presented in Fugures 23-28. Similar plant development patterns were demonstrated for all six irrigation treatments. Crown diameter and harvested plant volume increased steadily during the fall of 1981, stayed the same during the winter of 1981-82 (dormancy period), and increased rapidly during the spring of 1982. Leaf area index exhibited similar development patterns in the fall and spring, except leaf area actually decreased during the winter dormancy period. Total harvested dry matter (aboveground material plus roots) continued to increase from September 1981 to May 1982. The average dry matter for the three guayule cultivars for the I_1 (wet) through I_6 (dry) treatments in mid-May was as follows: 239 gm (0.53 lb.), 180 gm (0.40 lb.), 196 gm (0.43 lb.), 171 gm (0.38 lb.), 153 gm (0.34 lb.), and 125 gm (0.28 lb.).

Figures 29-34 show the resin and rubber content and yield for the first four harvest dates of the six irrigation treatments and three cultivars. Both resin and rubber concentrations continued to increase in the fall and winter of 1981-82; but in the early spring, percentages actually decreased when plant growth and development was accelerated. Little difference in the resin content was found between the six irrigation treatments as shown by the following values in order of decreasing water application for May 1982: 5.88% (I_1 treatment), 5.53% (I_2), 5.85% (I_3), 5.56% (I_4), 5.34% (I_5), and 5.97% (I_6). However, the rubber content did increase for the I_6 (dry) treatment as shown by the following percentages for May 1982: 4.23% (I_1 treatment), 3.76% (I_2), 4.25% (I_3), 4.2[illegible]% (I_4), 4.24% (I_5), and 5.31% (I_6). On the other hand, both resin and rubber production decreased significantly as the amount of water applied decreased. Resin yields in May 1982 were as follows: 757 kg/ha (675 lb/ac, I_1 treatment), 537 kg/ha (479 lb/ac, I_2), 619 kg/ha (522 lb/ac, I_3), 513 kg/ha (458 lb/ac, I_4), 442 kg/ha (395 lb/ac, I_5), and 404 kg/ha (360.4 lb/ac, I_6). Rubber yields in May 1982 were as follows: 544 kg/ha (486 lb/ac, I_1 treatment), 365 kg/ha (326 lb/ac, I_2), 449 kg/ha (400 lb/ac, I_3), 396 kg/ha (353 lb/ac, I_4), 350 kg/ha (313 lb/ac, I_5), and 359 kg/ha (320 lb/ac, I_6).

Based on the resin and rubber production and the soil water depletion (estimated ET) from transplanting to mid-May 1982, water-use efficiency (yield per ET amount) was calculated for the six irrigation treatments. The average water-use efficiency for resin yields averaged for the three cultivars were as follows: 5.23 kg/ha/cm (11.86 lb/ac/in., I_1 treatment), 4.67 kg/ha/cm (10.58 lb/ac/in., I_2), 5.74 kg/ha/cm (13.00 lb/ac/in., I_3), 5.75 kg/ha/cm (13.03 lb/ac/in., I_4), 5.21 kg/ha/cm (11.80 lb/ac/in., I_5), and 4.96 kg/ha/cm (11.26 lb/ac/in., I_6). The average water-use efficiency for rubber yields for the three cultivars were as follows: 3.76 kg/ha/cm (i8.52 lb/ac/in., I_1 treatment), 3.17 kg/ha/cm (7.19 lb/ac/in., I_2), 4.16 kg/ha/cm (9.43 lb/ac/in., I_3), 4.43 kg/ha/cm (10.04 lb/ac/in., I_4), 4.12 kg/ha/cm (9.35 lb/ac/in., I_5), and 4.41 kg/ha/cm (10.01 lb/ac/in., I_6). These water-use efficiency values for both resin and rubber production suggests that the I_3 or I_4 irrigation treatment may provide the highest economical benefit from a water supply viewpoint.

Since the resin and rubber yields were higher for the I_3 than the I_4 irrigation treatment, our present recommended irrigation regime would be the I_3 (medium) treatment. The measured seasonal water depletion on this treatment was 1079 mm (42.5 in.) for the thirteen-month growth period. As the age of the plants increases or the harvest date changes, the recommended production per water requirement could also be affected. Production data are still being analyzed for the July and September 1982 harvest dates.

Figures 35 and 36 depict the percentage of resin and rubber production, respectively, from large branches, small branches, and roots for the four harvest dates analyzed on the six irrigation treatments. Regardless of the harvest date, about 60 to 65% of the resin yield came from the small branches (above a 10-cm plant height), whereas the percentage from the roots continues to decrease and the percentage from the small branches (soil surface to a 10-cm height) has begun to increase slightly. In terms of rubber production, the portion obtained from small branches increased to about 60% by May 1982 for all irrigation treatments. On the other hand, the percentage of rubber yield obtained from the roots decreased to about 10% by May; and the percentage of rubber yield resulting from the large branches remained at near 20%. To date, the quantity of latex produced in the roots has been disappointing.

Plant minus air temperature differential for the six irrigation treatments and three cultivars as a function of time are presented in Figures 37 and 38. The cv. N565-II and 593 tended to show a 0.5 to 1°C higher foliage temperature than cv. 11591 in all the irrigation treatments; however, there were exceptions on some days. Also, Figures 39 and 40 indicate that the untreated plants had consistently higher temperatures than the bioregulated guayule plants. In most cases, the bioregulator (2-diethylaminoethyl 1-3, 4-dichlorophenylether) plants had cooler temperatures than the bioregulator B (2-diethylaminoethy 1-2, 4-dichlorophenylether).

Plant temperatures dropped rapidly following an irrigation, reached a minimum value a few days later, and then increased almost linearly with time (Figures 37, 38, 39, and 40). A temperature difference of 14 to 1 °C was observed between the well-watered and stressed plants on the drier (I_4, I_5, and I_6) treatments (Figures 38 and 40). In late June on the I_6 (dry) treatment, plant temperatures as high as 14°C above air temperature were recorded (Figure 38). On the other hand, plant temperatures in the I_1 (wet) treatment were seldom more than 1°C above air temperature before an irrigation (Figures 37 and 39). Also, plant temperatures remained consistently above air temperature during the mid-December to March period, even though adequate soil water was available on all irrigation treatments. The guayule plants are essentially dormant during this period of time.

Computed crop water stress indices (CWSI) versus time for the six irrigation treatments and three guayule cultivars are shown in Figures 41 and 42, following the procedures of Idso et al. (1981). On the I_1 (wet) treatment, the highest CWSI was about 0.8, whereas the CWSI was typically 0.2 before an irrigation. The highest CWSI with the I_3 (medium) treatment was 1.2, but the CWSI was between 0.6 and 1.0 before an irrigation in most cases. In comparison, the CWSI was as high as 1.5 on the I_4, I_5, and I_6 (medium and dry) treatments before an irrigation.

Diurnal patterns of CWSI for the I_1 (wet) and I_6 (dry) treatments for cv. 11591 are shown in Figures 43 and 44, respectively, along with the fraction of available soil water. In both irrigation levels the stress indices rapidly decreased following an irrigation, but an index of 0 was seldom reached in the dry treatment. Typically the minimum value after an irrigation was 0.2 on the I_6 treatment. A general pattern or agreement between the CWSI and fraction of available soil water (θ_{AF}) was evident. Figure 15 shows an equation that related CWSI and θ_{AF} just before an irrigation for cv. 11591 under all six irrigation treatments using 1982 data only. The equation, CWSI = 1.11 - 1.85 θ_{AF}, has an R^2 .75 and suggests that some variability can occur with either measurement.

Meteorological information such as solar radiation, net radiation, wind speed, air temperature, soil temperature, and relative humidity has been summarized and checked for 1982. However, crop coefficients for different irrigation scheduling equations or yield-growth models for the different irrigation treatments have not been completed.

Brawley, California

Greenhouse Procedures:

Because of death and stunted growth of guayule plants transplanted in March 1981 (which will be discussed further in the Results and Discussion Section), 9000 seedlings of three cultivars (11591, N565-II, and 593) were started in the U. S. Water Conservation Laboratory greenhouse. Clean seeds were washed and aerated for at least six hours, followed by two hours of a 0.25% sodium hypochlorite treatment. After the seeds had dried, the treated seeds were planted into growing flats using a potting mix of two parts sphagnum peat moss and one part by volume of vermiculite and covered with a thin layer of vermiculite. Once the seedlings were 10-14 days old, they were transferred into individual plastic net pots with a volume of 70 cm^3 using the same potting mix. The transplants were fertilized three times a week with a double Hougland's solution and mist-irrigated for two to three minutes daily. The greenhouse temperatures were controlled at a minimum of 25°C and a maximum of 35°C. When the plants were about three to four weeks old, they were transferred to the Brawley greenhouse for continued seedling growth. Periodically, the seedlings were clipped to a 6-cm height before field transplanting.

Field Procedures:

The field area surrounding the lysimeter was chiseled to a 90-cm (3-ft) depth on 50-cm (20-in.) centers in late September 1981. The field was then irrigated, disced, furrowed out, and raised beds constructed that were 1 m on center with a 50-cm top width. A small chisel was used to rip two rows on the raised beds that were about 36 cm (14 in.) apart and 45 cm (17-3/4 in.) deep. This chiseling or ripping procedure was used to insure adequate soil drainage and aeration during the establishment of guayule on the high water-holding capacity soil at the Imperial Valley Conservation Center, Brawley, California.

On October 22, seedlings of cv. N565-II were transplanted on 8 beds or 16 rows adjacent to the lysimeter and 6 rows within the lysimeter. The healthy plants of cv. 11591, that were previously planted in March 1981, were removed from the lysimeter treatment for resin and rubber analysis prior to the replanting. The seedlings were planted at a 36-cm (14 in.) spacing between plants along the row for a population of 54,000 plants/ha, as shown in Figure 46. A portable sprinkler irrigation system was used to apply twice-a-week water applications for 2-1/2 weeks, followed by once-a-week irrigations for a seven-week period. On December 3, seedlings of cv. 593 and 1159 were each transplanted on 4 beds or 8 rows on opposite sides of the N565-II cultivar. Weekly sprinkler irrigations were adequate for stand establishment for these later plantings because of the cooler daytime temperatures.

After the plants were establshed, the field was divided into three plots each 30 m (100 ft) x 17 m (55 ft) to provide for three furrow irrigation treatments. A large lysimeter, 3 m (100 ft) x 3 m (100 ft) and 1.5 m (5 ft) deep was located in the center of the field and was used to determine daily evapotranspiration (ET) rates during the development of guayule plants. One neutron access tube was placed in the lysimeter, and three tubes per irrigation treatment (one per guayule cultivar) were placed to a 180-cm (6-ft) depth in the adjoining plots. The planned furrow irrigation treatments consisted of a medium treatmen in and around the lysimeter, while wetter and drier treatments were maintained away from the lysimeter. The three field irrigation treatments were: (wet) irrigate when 30% of the available soil water has been depleted; (medium) irrigate when 40% of the available soil water has been depleted; and (dry) irrigate when 50% of the available soil water has been depleted. The 0-110-cm (nearly 4 ft) soil depth was use to schedule irrigations and calculate soil water depletions in 1982. O this heavy clay loam soil, field capacity and wilting point have been estimated at 40% and 15% by volume, which means that the available soil water is about 250 mm of water in the top 1 m of soil.

Water applications at each irrigation were measured by a propeller-type water meter, and aluminum gated pipe was used in delivering water to th individual plots surrounded by early border dikes covered with plastic film. Neutron meter readings were taken weekly, and plant height measurements were made monthly. Meteorological observations included daily maximum and minimum air temperatures average relative humidity, total wind movement, Class A pan evaporation, precipitation, total solar radiation, and net radiation. These measurements were recorded at about 0900 PST on a standard Weather Bureau station with Bermuda grass cover located about 400 yards from the guayule plots on the Imperial Valley Experiment Station.

Results and Discussion:

As discussed in the 1981 Annual Report, better than 98% survival was achieved at Brawley on the first planting using furrow irrigation practices. However, irreversible damage occurred on the plants surrounding the lysimeter on June 12-13, 1981, because the irrigation water was allowed to stand over 12 hours. High air temperatures of 42 and 43°C for the two days may also have contributed to the problem. Plant loss were the greatest in the low-lying areas of the field where over 75% of the plants died in a very short period of time. Waterlogging and/or oxygen deficiency, based on visual observations, was the primary reason f the catastrophe. None of the plants showed damage in the lysimeter because of the better drainage characteristics in the lysimeter. Table 4 shows the harvest data from the seven-month-old, cv. 11591 plants th were removed from lysimeter prior to the replanting of the field and lysimeter. Total aboveground dry matter was 133 gm (0.29 lb)/plant; resin content was 5.63%; resin yield was 443 kg/ha (396 lb/ac); rubber content was 1.75%; and rubber yield was 113 kg/ha (101 lb/ac). The seasonal ET based on lysimeter measurements was 1490 mm over the March through October period, with minimal water stress exhibited by the plants.

With the second planting of guayule in the fall of 1981, Table 3 shows that only 98 mm (3.86 in.) of water as applied on the heavy-textured soil for transplant establishment when temperatures were relatively cool for Brawley. Maximum and minimum temperatures averaged 30°C and 11°C, respectively, during the first two weeks. Better than a 98% transplant survival was again obtained.

Figure 47 presents the plant heights of the three guayule cultivars, three irrigation treatments, and lysimeter. Plant height decreased slightly from the wet to dry irrigation treatment for all three cultivars. By the time the plants were 14 months old (December 1982), cv. 11591 was slightly taller than N565-II, followed by 593. The N565-II plants in the lysimeter were between the heights of the same cultivar for the medium and dry irrigation treatments in the field. Changes in the soil water content averaged for the three cultivars versus time showed that furrow irrigations were actually applied when 24, 32, and 34% of the available soil water was depleted in the 0-110 cm soil depth for the wet, medium, and dry treatments (Figures 48-50). Higher depletion rates were difficult to achieve because of the extensive soil cracking and visual plant stress on the medium and dry treatments in the field.

Table 4 lists the amounts of furrow irrigations applied on the three irrigation and lysimeter treatments. Furrow irrigations commenced on March 2; and totaled 1091 mm (42.9 in.), 927 mm (36.5 in.), and 675 mm (26.6 in.) for the wet, medium and dry treatments in 1982. The furrow irrigations in the lysimeter amounted to 1151 mm (45.3 in.). Average soil water depletion rates for the three cultivars and three irrigation treatments are presented in Figures 51-53. The estimated seasonal water used (ET) from March through December 1982 for each irrigation treatment in order of decreasing water applications was 880 mm (34.6 in.), 770 mm (30.3 in.), and 730 mm (28.7 in.). During the same period of time, the seasonal ET was measured at 1360 mm (53.5 in.) in the lysimeter (Figure 56). For the entire 14-month period, the seasonal ET based on daily lysimeter measurements totaled 1520 mm (59.8 in.) from October 1981 through December 1982. The water balance in the lysimeter included 98 mm (3.85 in.) of sprinkler irrigation water, 1151 mm (45.3 in.) of furrow irrigation water, 90 mm (3.55 in.) of precipitation, and 181 mm (7.1 in.) of reduced soil water storage.

The patterns of soil water depletions were similar between the field (Figures 51-53) and the lysimeter (Figure 54). A summer cutout period or reduced ET rate occurred in all cases, but was affected by the plant development and irrigation schedule. On the wet and medium treatments, this cut-out period occurred in August, whereas depletion rates decreased in late June through July on the dry treatment and the lysimeter. The peak ET rate on the wet treatment was estimated at about 7 mm/day (0.28 in./day) in mid-July compared with 12.5 mm/day (0.49 in./day) in mid-August for the lysimeter. Crop coefficients comparing the measured ET to the reference ET for the Bermuda crop as calculated from various meteorological equations have not been fully determined; however, the seasonal (October 1981 through December 1982) pan coefficient was 0.49 for the lysimeter.

Whole plant samples (tops plus roots) were analyzed for resin and rubber production in September and December 1982. The harvest data average for total dry matter was 118 gm (0.26 lb)/plant; rubber content was 1.89%; and rubber yield was 120 kg/ha (107 lb/ac) with no significant difference between irrigation treatments (Table 2) at 11 months of age (September 1982). However, a trend of increased resin content and yield occurred for wet over the dry treatment. The resin content and yield for the wet treatment was 6.44% with 443 kg/ha (396 lb/ac), whereas the dry treatment had 4.90% with 275 kg/ha (246 lb/ac) at this young age. Hopefully, rubber concentrations will begin increasing on this heavy soil since plant growth and development has been excellent in late 1982.

Yuma, Arizona

Greenhouse Procedures:

Six thousand seedlings of each cv. 11591, N565-II, and 593 were produced at the U. S. Water Conservation Laboratory in a manner similar to that described for the Brawley, California, experiment. Guayule seeds were started in the greenhouse during the first week of October 1981. The seedlings were clipped several times before transplanting to the field at a height of 6 cm (2.5 in.).

Field Procedures:

The southwestern United States has a large acreage of marginal agricultural land with limited water supplies. The Yuma Mesa Experiment Station, Yuma, Arizona, represents a typical marginal land conditions with a calcareous sandy (91 to 94% sand) soil. Information is needed on the cultural practices, irrigation, and nitrogen management under desert environments. The primary objective of this investigation is to determine guayule irrigation and minimum and maximum fertility requirements on a marginal soil with limited surface and groundwater supplies.

Before transplanting the guayule seedlings at Yuma, Terrachlor Super X (Pentachloronitrobenzene, 10%, plus 5-ethoxy-3 trichloromethyl-1,2,4 thiadiazole, 2.5%), which is a combination fungicide of Terrachlor for Fusarium and Rhizoctonia and Terrazole for Pythium control, was applied at 168 kg/a (150 lb/ac) and incorporated. Treeblesuperphosphate (0-45-0) fertilizer was also applied at 498 kg/ha (444 lb/ac) or 224 kg/ha (200 lb/ac) of P_2O_5.

On January 19-20, the guayule seedlings were transplanted using a mechanical transplanter following the field plan shown in Figure 55. The 4[illegible] rows were spaced 56 cm (22 in.) apart on the flat, and the plants were spaced 36 cm (14 in.) apart along the row for a population of 49,500 plants/ha (20,000/ac). There was a total of 13 irrigation plots with each being about 11 m (36 ft) long and 26 m (85 ft) wide. The entire experiment was about 0.4 ha (1 ac) in size and the total row length was approximately 170 m (560 ft) long.

After the seedlings were transplanted, a uniform spray bar on the automated sprinkler system was used to precisely irrigate the young seedlings. The sprinkler irrigation system is a self-moving, linear system that operates perpendicular to the east-west row direction. The pumping plant walks along a concrete ditch to obtain a continuous water supply. The versatility of the system makes it especially suitable for an irrigation and nitrogen management experiment. Maximum speed of the system is 2.1 m/min. (7 ft/min.), and it can operate forward or reverse at any speed between 5 and 100% of this maximum speed. During the establishment period, 11 kg/ha (10 lb/ac) of nitrogen was applied through the sprinkler system on February 9, 16, March 2, 11, and 31, for a total of 56 kg/ha (50 lb/ac) of nitrogen. On May 14, the irrigation system was changed from uniform irrigations to the different irrigation and nitrogen treatments.

The different irrigation treatments are accomplished by selecting a separate spray bar that has different nozzles of different orifice sizes. The amount of water applied during each irrigation is determined by measuring the time required to travel a selected distance. The different nitrogen application rates are accomplished by using different size orifices in each plot to meter the nitrogen into the irrigation water. Water samples are collected when the nitrogen is injected to verify the correct rate of nitrogen is being applied. The amount of nitrogen applied per application can vary from 11 to 67 kg/ha (10 to 60 lb/ac) by changing the machine travel speed from 100 to 15%. High nitrogen applications result in high water applications since both are controlled by the machine travel speed. The nitrogen fertilizer applied in the irrigation water raises the total dissolved solids by about 100 mg/ℓ. Colorado river water is used for irrigations and averages about 900 mg/ℓ (1.4 decisiemens/cm) total dissolved solids.

There are a total of nine treatments in this experiment which are defined by a statistical design with the center treatment replicated five times. This gives a total of 13 plots, where different levels of water and nitrogen are applied. The experimental design is called a central composite rotatable statistical design with two variables, water and nitrogen. The water levels are being varied from 50 to 150% water applied (WA) and nitrogen levels vary from 33 to 16% nitrogen (N)/ac. As noted in Figure 55, the water and nitrogen rates specified in this experiment are as follows:

Treatment	% WA	%N
T_1	50	100
T_2	65	53
T_3	65	147
T_4	100	33
T_5	100	100
T_6	100	167
T_7	135	53
T_8	135	147
T_9	150	100

The frequency of irrigation was set at biweekly for January and February, weekly from March through November and biweekly in December 1982. The 100% WA from May through December 1982 was estimated from th I_2 irrigation treatment for the previous year at Mesa, Arizona, plus a 10% leaching fraction for salinity control and deep percolation losses. The Mesa guayule experiment is one year older; and the seasonal soil water depletion from May 15 to December 30, 1981, was 755 mm (see 1981 Annual Report). Therefore, the 100% WA for the same period in 1982 was specified at about 830 mm (33 in.) for the Yuma guayule experiment. The amount and timing of the 100% N treatment was specified at 56 kg/ha (50 lb/ac) applied in early fall (September) and 56 kg/ha (50 lb/ac) applie in early spring (late March or early April) as new growth commences. In 1982, the first differential amounts of nitrogen fertilizer were applie in two applications (each 28 kg/ha) on September 8 and 22.

In addition to the water and nitrogen treatments, there are five plants/ row for a total of 225 plants/treatment plot that are sprayed with bio- regulators on two-month intervals during the active growing season. The three bioregulator compounds are 2-diethylaminoethyl 1-3, 4-dichloro- phenylether; 2-diethylaminoethyl 1-2, 4-dichlorophenylether and N-meth benzylhexylamine, which were applied on April 17, June 17, August 8, a October 21 in 1982. Each individual bioregulator plot includes 25 plants/cultivar and represent an area of about 1.8 x 2.8 m (5.8 x 9 ft

Meteorological factors affecting ET are being monitored beginning on June 17 by portable stations equipped with CR 21 microloggers. Weather data are determined on the T_5 treatment for guayule and on an adjacent alfalfa field for a reference crop. On guayule, wind speed is deter- mined at 2 m (6.6 ft) height; net radiation, air temperature, and rela- tive humidity at 1.5 m (4.9 ft) height; net radiation at 1/2 the plant height; and soil temperature at 1-cm (0.8-in.) depth below the soil su face. On the alfalfa, solar radiation and wind speed are determined at 2-m (6.6-ft) height; net radiation, air temperature, and relative hum- diity at 1.5-m (4.9-ft) height; and soil temperature at 1 cm (0.8 in.) below the soil surface. Starting in October, neutron moisture measure- ments were begun on ten neutron access tubes at a 3-m (10-ft) soil depth with two each located in the N565-II cultivars on the five T_5 treatmen plots. Total plant nitrogen uptake and nutrient levels of guayule pla tissues for the five irrigation and five nitrogen treatments will periodically be obtained. Plant heights were obtained for the three cultivars and three and nine treatment combinations on July 1, August October 22, and December 2, 1982. Also, harvest data will be taken at least two times per year beginning in the fall of 1982. Two plants per cultivar will be selected for each plot and harvest date for a total o 78 whole plants with roots. The final harvest data is now scheduled for late 1985 or early 1986.

RESULTS AND DISCUSSION:

An excellent transplant survival of better than 98% was obtained on th sandy soil. Figure 56 shows the plant heights for the three guayule cultivars (11591, N565-II, and 593) and five water applied (WA) treatments (the five nitrogen treatments were averaged) in 1982. Plant heights were consistent with reduced irrigation amounts from the 150 to 50% WA for all three cultivars. Cultivar 11591 is typically taller than cv. N565-II, followed by cv. 593, except for the 50% WA, where cv. N565-II is slightly taller than cv. 11591. Plant harvest data were taken on November 5, 1982, in terms of plant development and resin and rubber production. Water application, soil moisture, and plant nutrient data have not been fully analyzed at this date.

SUMMARY AND CONCLUSIONS:

Three comprehensive guayule irrigation experiments are being conducted on a medium-textured soil at Mesa, Arizona, on a heavy-textured soil at Brawley, California, and a coarse-textured soil at Yuma, Arizona. The Mesa location was planted in the spring of 1981; the Brawley location was replanted in the fall of 1981; and the Yuma location was planted in early 1982. Better than 95 to 98% transplant survival was obtained at all three locations and three cultivars (11591, N565-II, and 593). The key to successful transplant establishment was careful water management with either sprinkler or furrow irrigation systems plus proper tillage practices.

At Mesa, Arizona, drought-tolerant guayule plants depleted water in the first two seasons of growth in relation to the availability of soil water and environmental demands. Where water applications were high, water use was high; whereas, with low water application rates, soil water depletion was low. The seasonal water depletion for the three cultivars averaged 3000, 2410, 2040, 1720, 1470, and 1520 mm from May 1981 through December 1982, in decreasing order of water applications for six irrigation treatments. Soil water content profiles indicated that guayule roots extracted water to depths greater than 180 cm by the end of the 20th month. Plant height, biomass, leaf area, and resin and rubber yield decreased significantly among the three wetter treatments, while a small decrease was noted among the three drier treatments. Periodic plant harvests showed that rubber production was about 540 kg/ha with 4.2% rubber concentration for the highest water application; whereas, rubber production averaged nearly 360 kg/ha with 5.3% rubber concentrations for the lowest water application by May 1982. About 60% of the rubber production was obtained from the smaller branches above a 10-cm plant height. Guayule plant temperature measurements with infrared thermometers followed the onset, duration, and relief of moisture stress. Crop water stress indices greater than 1.0 were obtained, particularly on the dry treatment. Additional research is needed to resolve this behavior.

At Brawley, California, seasonal evapotranspiration based on lysimeter measurements was 1490 mm over the March through October 1981 period, with minimal water stress exhibited by the plant. Outside the lysimeter, young guayule plants were found to be sensitive to waterlogging under high temperatures and high water-holding soils where irreversible damage occurred. After replanting in the lysimeter and field plots, the seasonal evapotranspiration based on daily lysimeter measurements totaled 1520 mm from October 1981 through December 1982. At 11 months of age (September 1982), rubber production averaged 120 kg/ha at 1.9% rubber content for the three cultivars (11591, N565-II, and 593), with no large production difference between wet, medium, and dry irrigation treatments buffering the large lysimeter. The seasonal soil water depletion (estimated ET) for each field irrigation treatment in order of decreasing water applications was 880, 770, and 730 mm from March through December 1982.

At Yuma, Arizona, excellent transplant survival (better than 98%) was obtained on a sandy soil by careful water applications using a linear-move sprinkler irrigation system in January 1982. Five irrigation and five nitrogen levels have been initiated since early summer. Equipment for climatic and soil water measurements has been installed, and periodic plant sampling for growth, nutrient status, and rubber and resin content has begun.

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Table 1. Water application amounts applied using the furrow method on the six different irrigation treatments plus total precipitation at Mesa, Arizona, 1982.

Irrigation Treatment											
Irrig. Date	Irrig. Amount (mm)	Irrig. Date	Irrig. Amount (mm)	Irrig. Date	Irrig. Amount (mm)	Irrig. Date	Irrig. Amount (mm)	Irrig. Date	Irrig. Amount (mm)	Irrig. Date	Irrig. Amount (mm)
I_1		I_2		I_3		I_4		I_5		I_6	
FEB 20	178	MAR 04	174	MAR 10	177	MAR 25	175	APR 09	176	MAY 14	169
APR 16	171	APR 23	169	MAY 14	169	MAY 26	168	JUN 24	168	JUL 09	166
MAY 14	169	MAY 26	168	JUN 24	168	JUL 06	161	AUG 31	164	SEP 16	165
JUN 2	176	JUN 25	163	JUL 30	166	AUG 11	160	NOV 3	170		
JUN 25	163	JUL 22	156	AUG 31	164	OCT 1	182			Total	500 mm
JUL 06	161	AUG 11	160	OCT 22	168			Total	678 mm		(19.7 in.)
JUL 22	156	SEP 13	148			Total	846 mm		(26.7 in.)		
AUG 05	165	OCT 08	183	Total	1212 mm		(33.3 in.)				
AUG 31	164	NOV 15	178		(39.8 in.)						
SEP 16	165										
OCT 08	183	Total	1499 mm								
NOV 03	170		(59.0 in.)								
Total	2021 mm (79.6 in.)										

1982 precipitation = 256 mm (10.0 in.)

Table 2. Harvest data for October 1981 and September 1982 at Brawley, California.

Irrigation Treatment	Crown Diameter (cm)	Aboveground Harvested Volume ($cm^3 \times 10^3$)	Total Dry Matter (gm/plant)	Resin Content (%)	Resin Yield (kg/ha)	Rubber Content (%)	Rubber Yield (kg/ha)
			October 23, 1981 (Initial Planting, March 1981)				
Lysimeter	2.1	43.9	133	5.63	334	1.76	113
			September 15, 1982 (Replanted October 1981)				
Wet	2.0	51.1	127	6.44	443	1.75	121
Medium	2.2	54.1	123	5.00	328	1.87	122
Dry	2.0	34.3	104	4.90	275	2.04	113

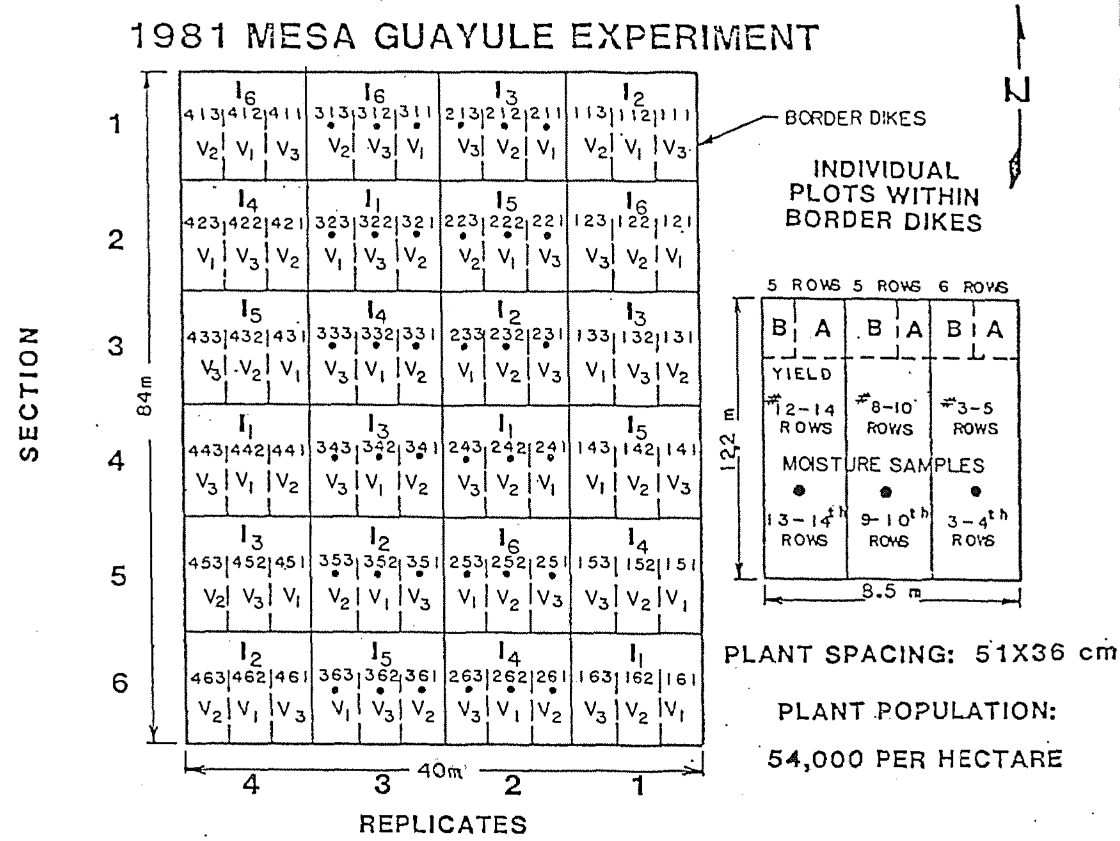
Table 3. Water application amounts applied for the establishment of guayule at Brawley, California, 1981-1982.

Irrigation Date	Irrigation Method	Water Applied (mm)
OCT 27	Sprinkler	20
OCT 30	Sprinkler	16
NOV 03	Sprinkler	8
NOV 10	Sprinkler	4
NOV 13	Sprinkler	7
NOV 25	Sprinkler	5
DEC 04	Sprinkler	3
DEC 10	Sprinkler	4
DEC 17	Sprinkler	7
DEC 23	Sprinkler	8
JAN 08	Sprinkler	9
JAN 25	Sprinkler	7
Total water applied for plant establishment		98 mm (3.86 in.)

Table 4. Water application amounts applied using the furrow method on three irrigation treatments and the lysimeter in 1982, plus total precipitation and sprinkler irrigations, 1981-82, at Brawley, California.

Irrig. Date	Irrig. Amount (mm)	Irrig. Date	Irrig. Amount (mm)	Irrig. Date	Irrig. Amount (mm)	Irrig. Date	Irrig. Amount (mm)
			Furrow Irrigation Treatments				
Wet		Medium		Dry		Lysimeter	
MAR 02	114	MAR 02	114	MAR 02	114	MAR 02	130
APR 23	114	APR 23	114	APR 23	114	APR 23	109
MAY 18	106	MAY 26	106	JUN 04	118	MAY 27	107
JUN 11	94	JUL 01	137	JUL 19	104	JUN 29	161
JUL 08	129	JUL 28	97	AUG 16	78	JUL 27	128
JUL 28	109	AUG 16	91	SEP 23	83	AUG 09	98
AUG 09	64	SEP 07	80	OCT 28	64	AUG 25	95
AUG 27	84	SEP 23	53		——	SEP 07	79
SEP 17	85	OCT 14	71	Total	675 mm (26.6 in.)	SEP 23	79
OCT 07	71	NOV 05	64			OCT 14	95
OCT 29	51		——			NOV 05	70
DEC 02	70	Total	927 mm (36.5 in.)				——
	——					Total	1151 mm (45.3 in.)
Total	1091 mm (42.9 in.)						

Precipitation (OCT 27, 1981 - DEC 30, 1982) = 90 mm (3.55 in.)
Sprinkler Irrigations (OCT 27, 1981 - JAN 25, 1982) = 98 mm (3.85 in.)



LEGEND:

IRRIGATION TREATMENTS

I_1 =60% SMD* -BLACK
I_2 =80% SMD-BLUE
I_3 =100% SMD-GREEN
I_4 =100% SMD PLUS 2 WEEKS-RED
I_5 =100% SMD PLUS 4 WEEKS-WHITE
I_6 =THREE IRRIG. PER YEAR-YELLOW

CULTIVARS

V_1 =593
V_2 =N565-II
V_3 =11591

BIOREGULATORS

A=2-DIETHYLAMINOETHYL 1-3,4-DICHLOROPHENYLETHER
B=2-DIETHYLAMINOETHYL 1-2, 4-DICHLOROPHENYLETHER

* SOIL MOISTURE DEPLETION IN A 0 - 120 cm SOIL DEPTH

● LOCATION OF 36 NEUTRON ACCESS TUBES TO A 300 cm SOIL DEPTH

Figure 1. Plot diagram, irrigation treatments, cultivars, and bioregulators for guayule planted in April 1981, at Mesa, Arizona.

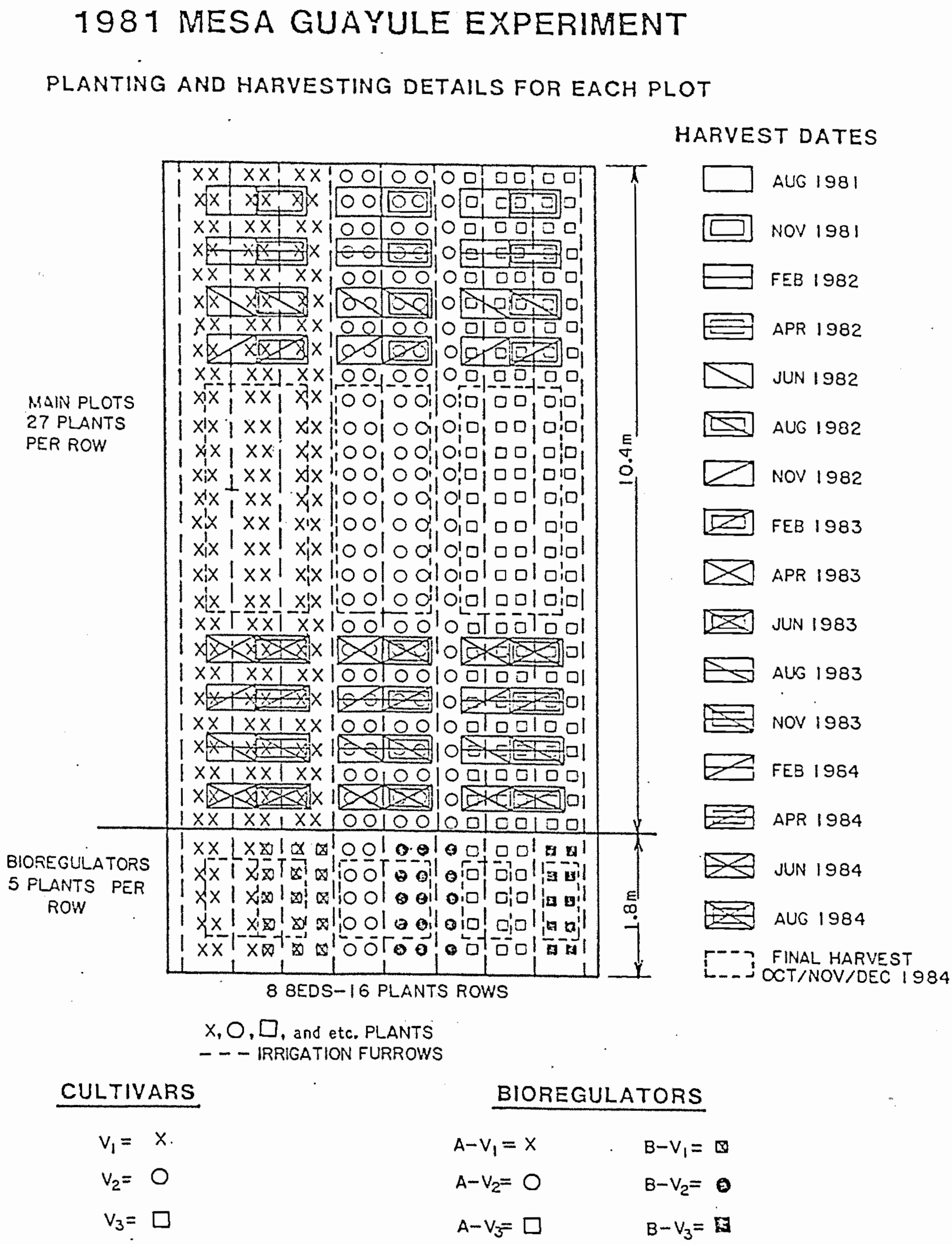


Figure 2. Details of planting and periodic harvests at Mesa, Arizona.

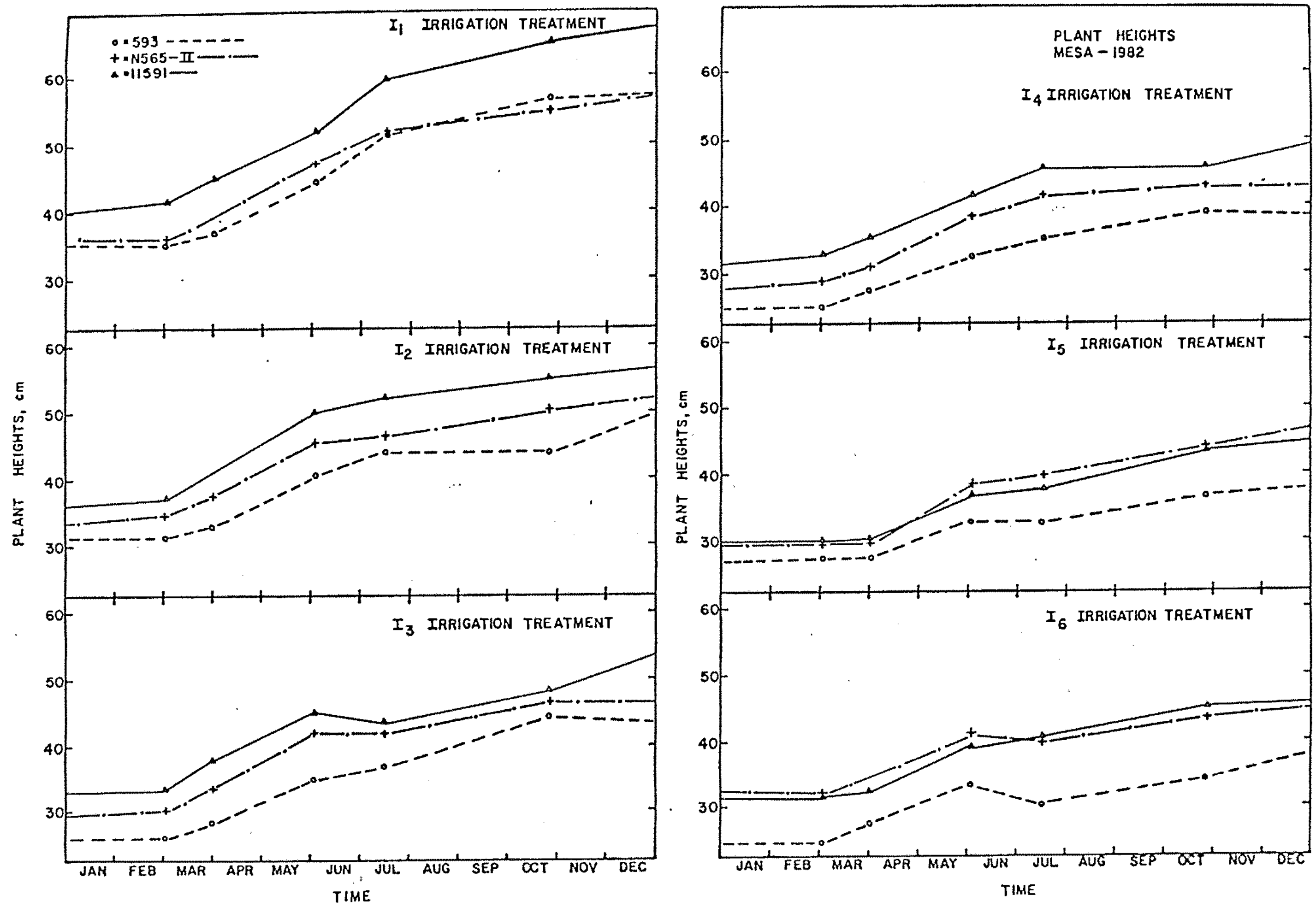


Figure 3. Average plant heights for three guayule cultivars and six irrigation treatments at Mesa, Arizona, 1982.

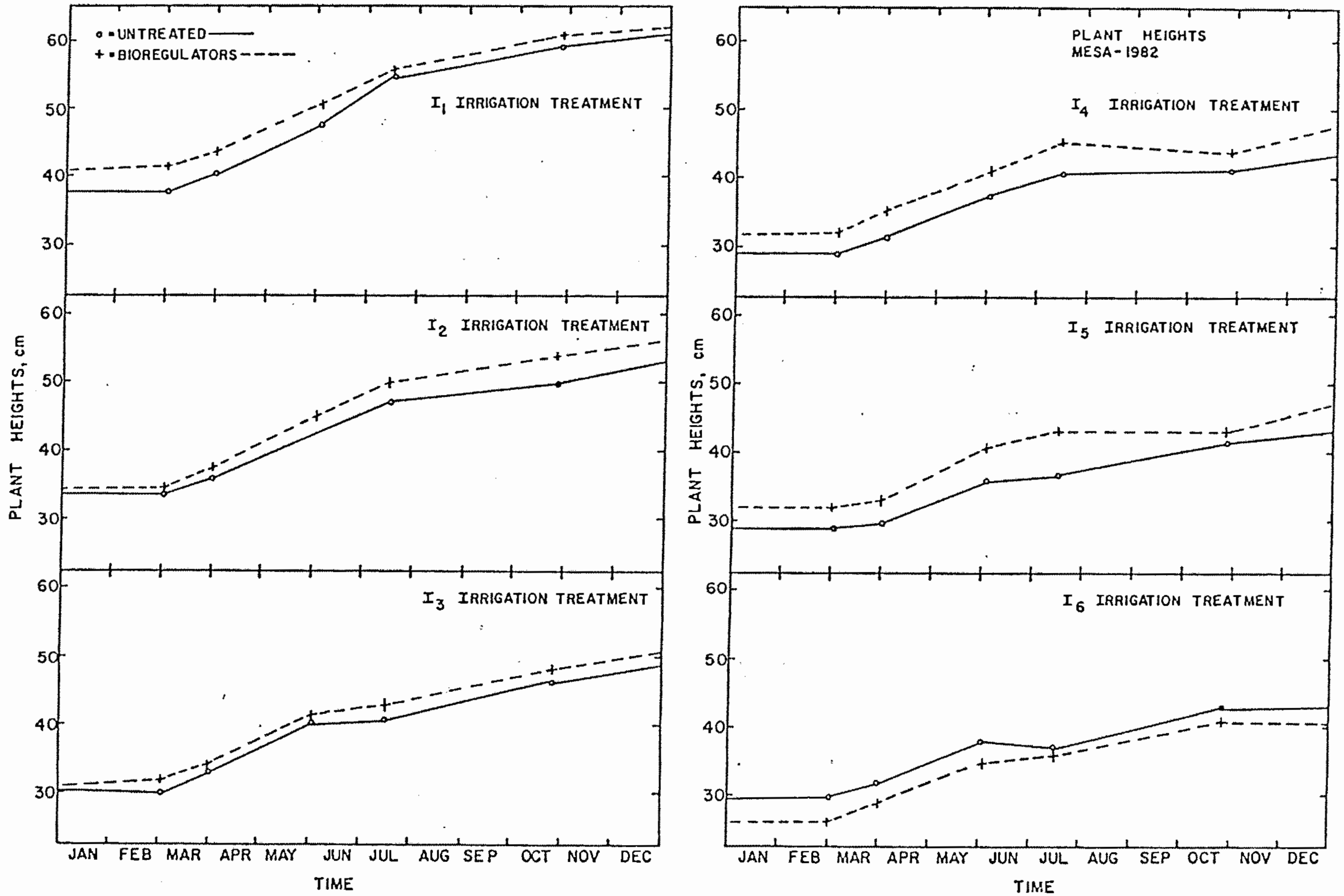


Figure 4. Average plant heights for untreated and bioregulated guayule plants at Mesa, Arizona, 1982.

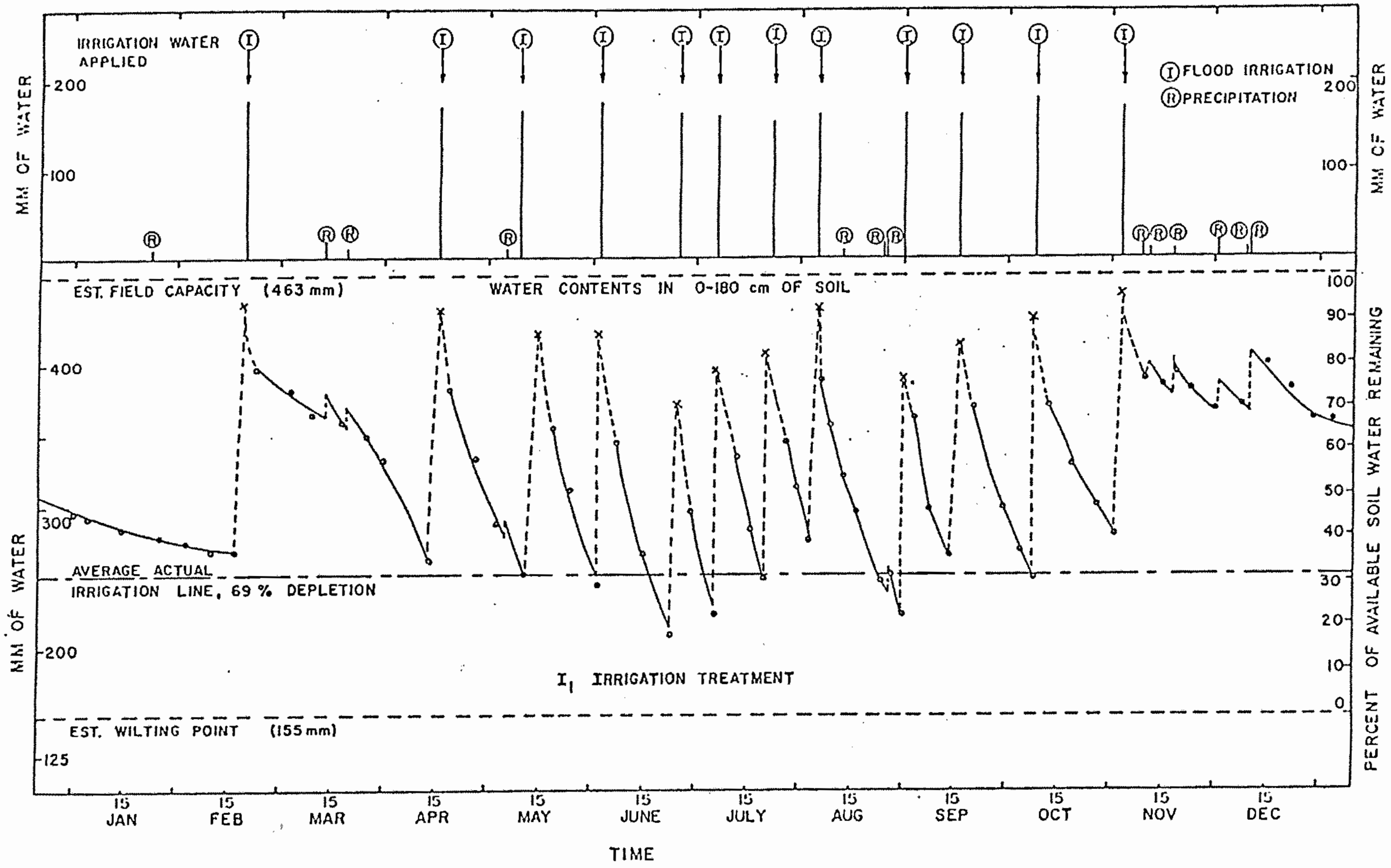


Figure 5. Irrigation water applied and average soil water contents for the I_1 irrigation treatment at Mesa, Arizona, 1982. (Twelve irrigations were given after 69% of the available soil water was depleted. In

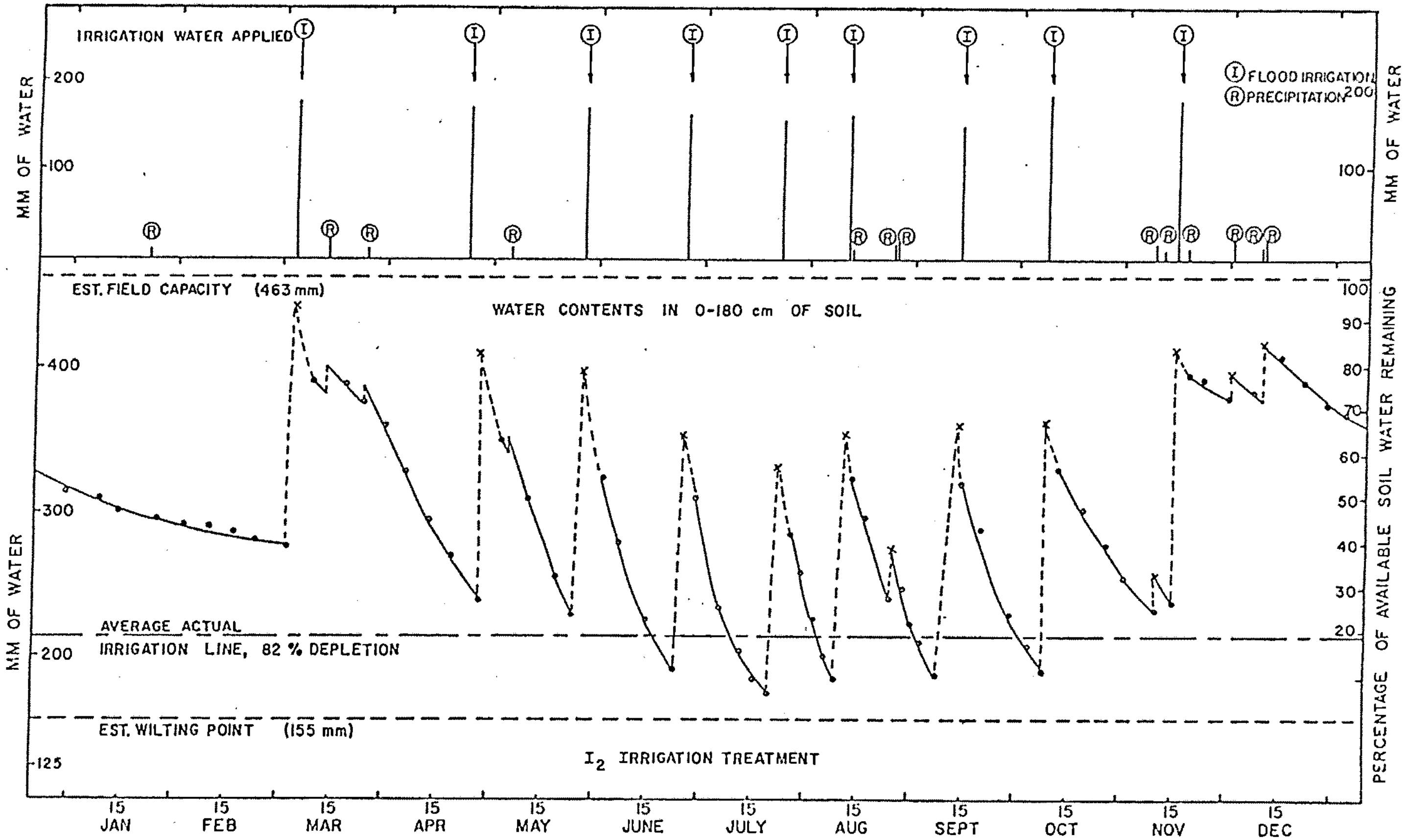


Figure 6. Irrigation water applied and average soil water contents for the I_2 irrigation treatment at Mesa, Arizona, 1982. (Nine irrigations were given after 82% of the available soil water was depleted in the 0-180-cm depth).

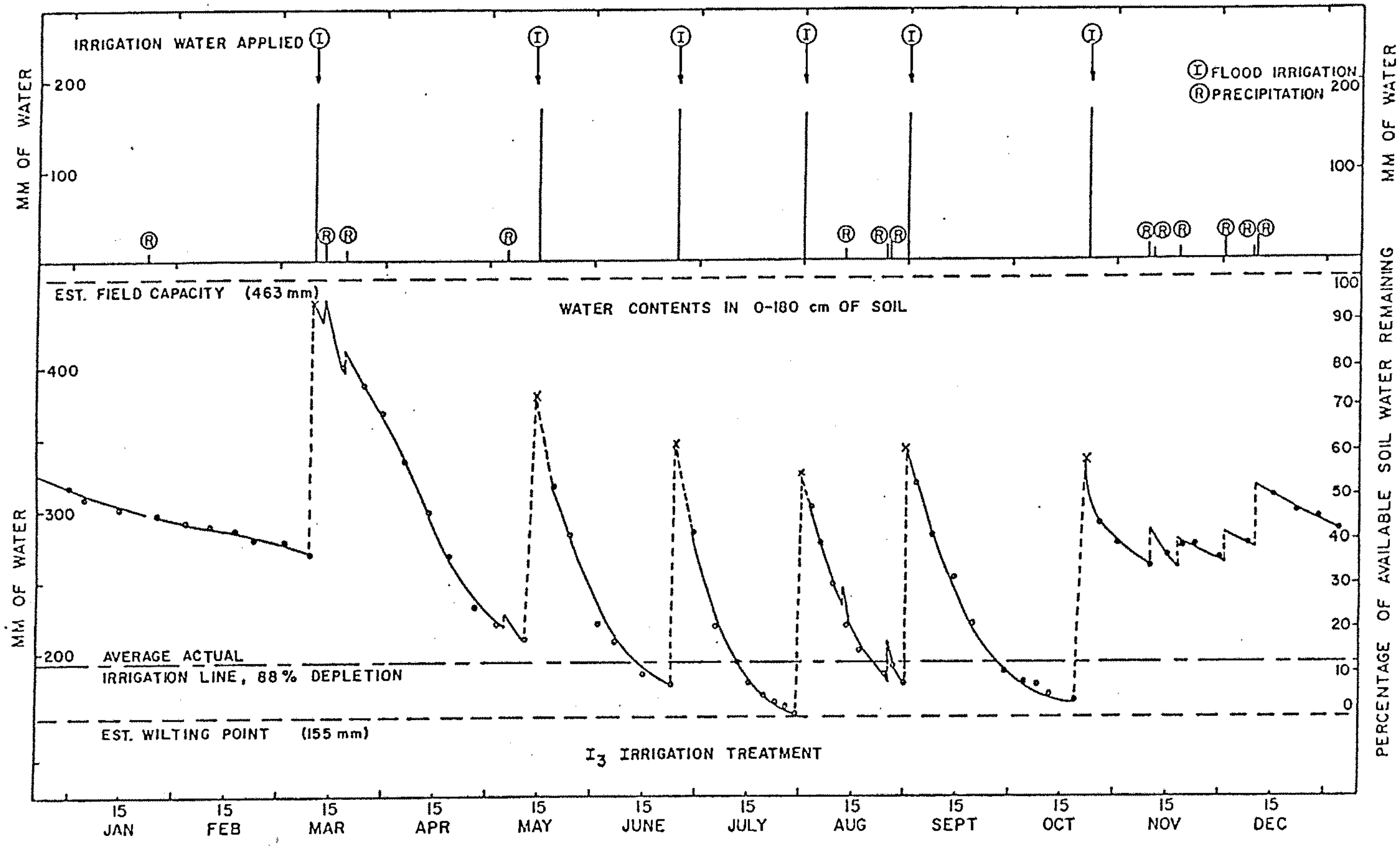


Figure 7. Irrigation water applied and average soil water contents for the I_3 irrigation treatment at Mesa, Arizona, 1982. (Six irrigations were given after 88% of the available soil water was depleted in the 0-180-cm depth).

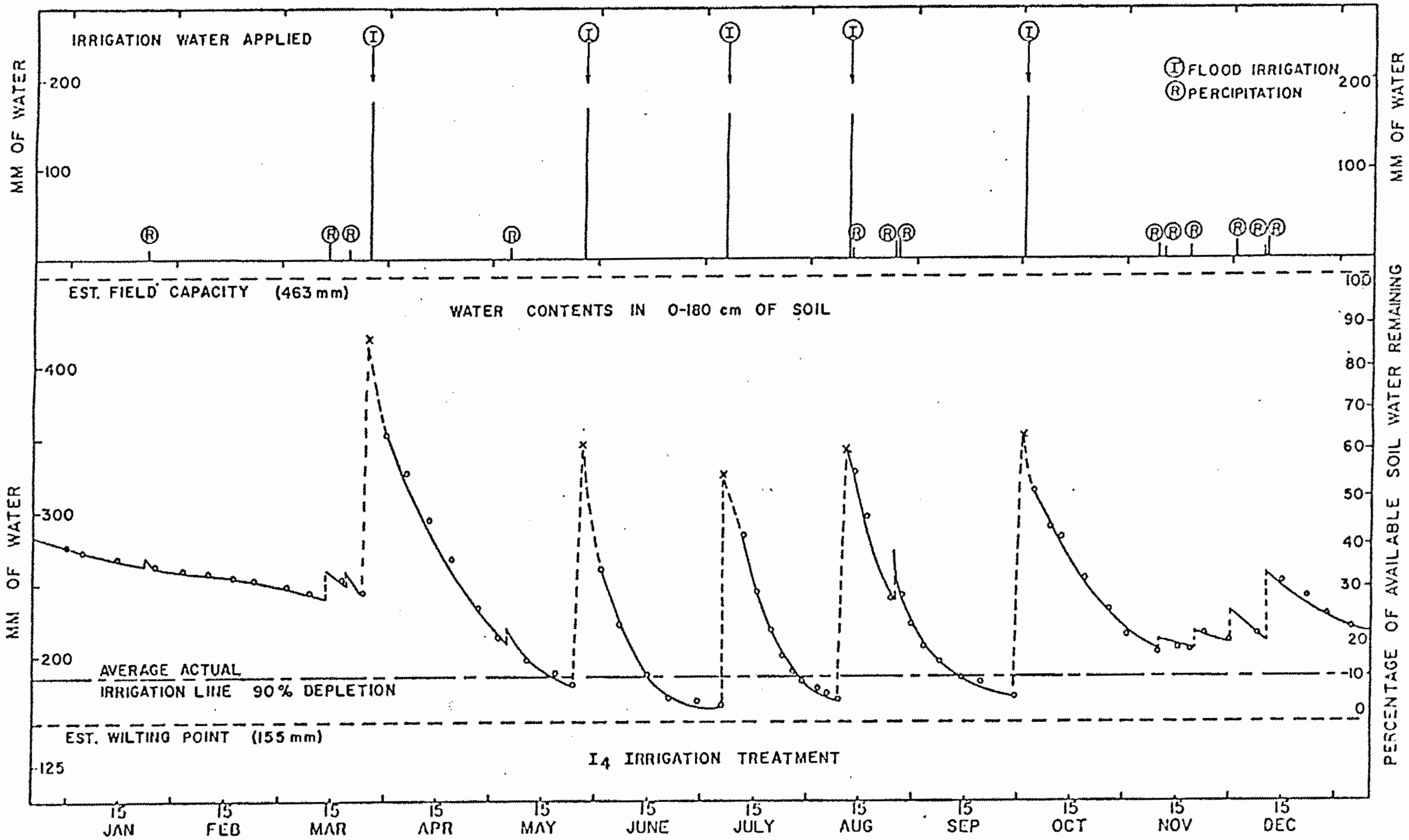


Figure 8. Irrigation water applied and average soil water contents for the I_4 irrigation treatment at Mesa, Arizona, 1982. (Five irrigations were given after 90% of the available soil water was depleted in the 0-180-cm depth).

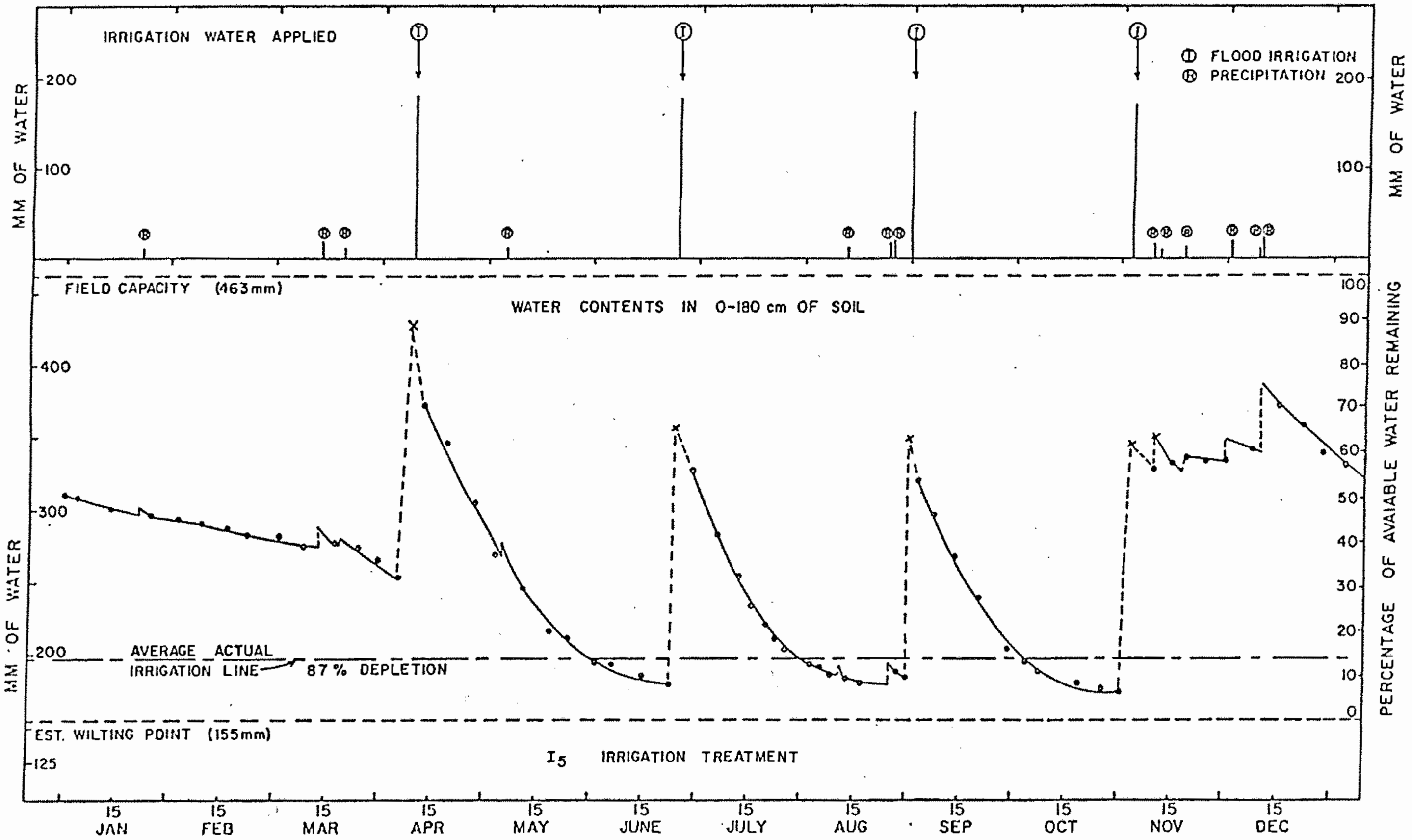


Figure 9. Irrigation water applied and average soil water contents for the I5 irrigation treatment at Mesa, Arizona, 1982. (Four irrigations were given after 87% of the available soil water was depleted in the 0-180-cm depth).

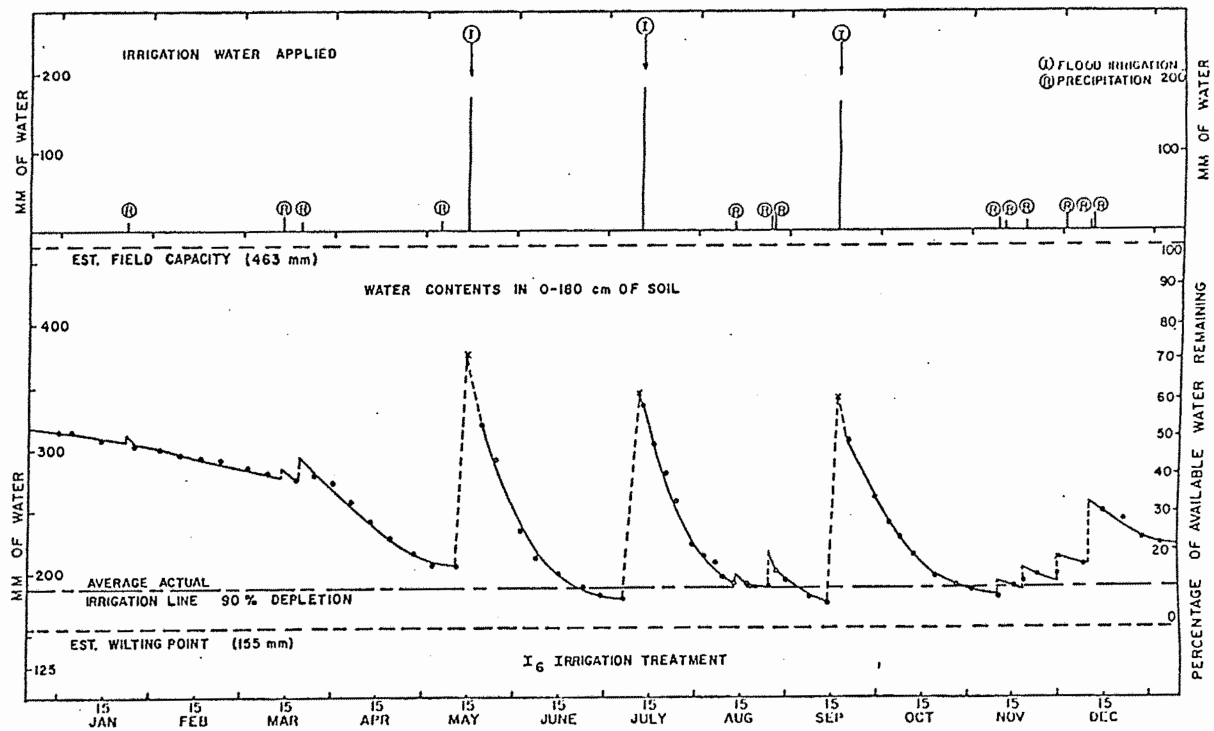


Figure 10. Irrigation water applied and average soil water contents for the I_6 irrigation treatment at Mesa, Arizona, 1982. (Three irrigations were given after 90% of the available soil water was depleted in the 0-180-cm depth).

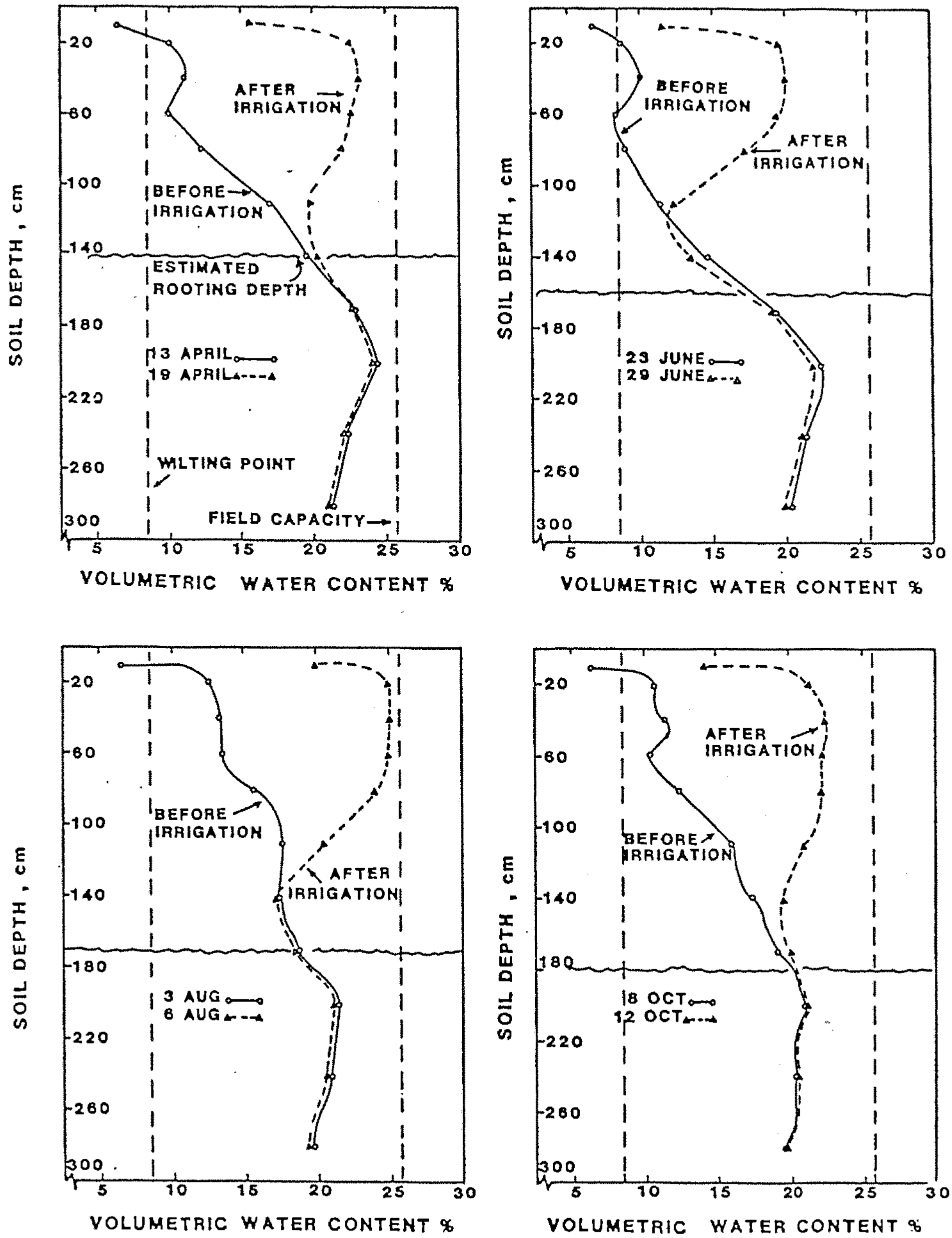


Figure 11. Soil water content profiles and estimated plant rooting depths for selected dates with the I_1 irrigation treatment at Mesa, Arizona, 1982.

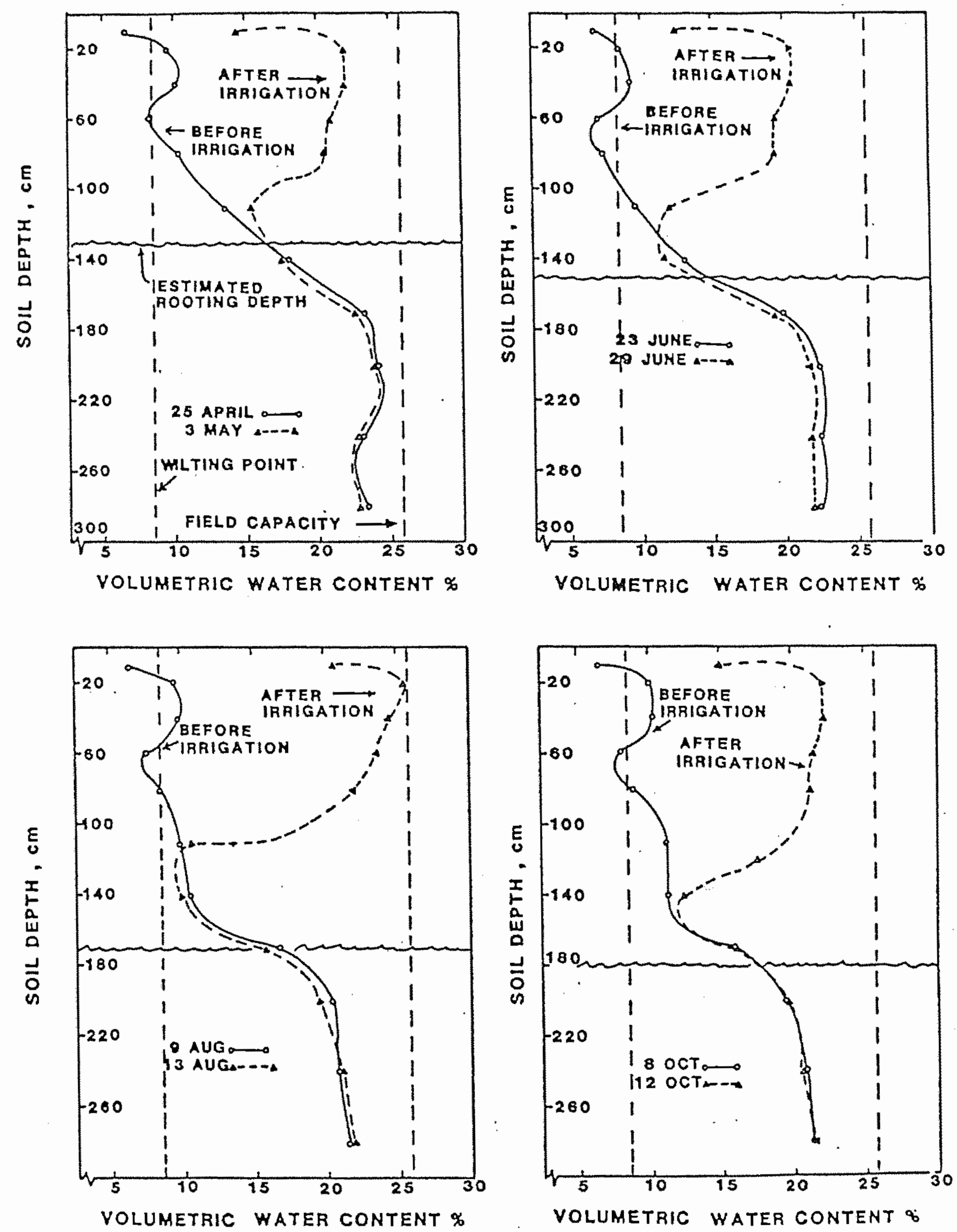


Figure 12. Soil water content profiles and estimated plant rooting depths for selected dates with the I_2 irrigation treatment at Mesa, Arizona, 1982.

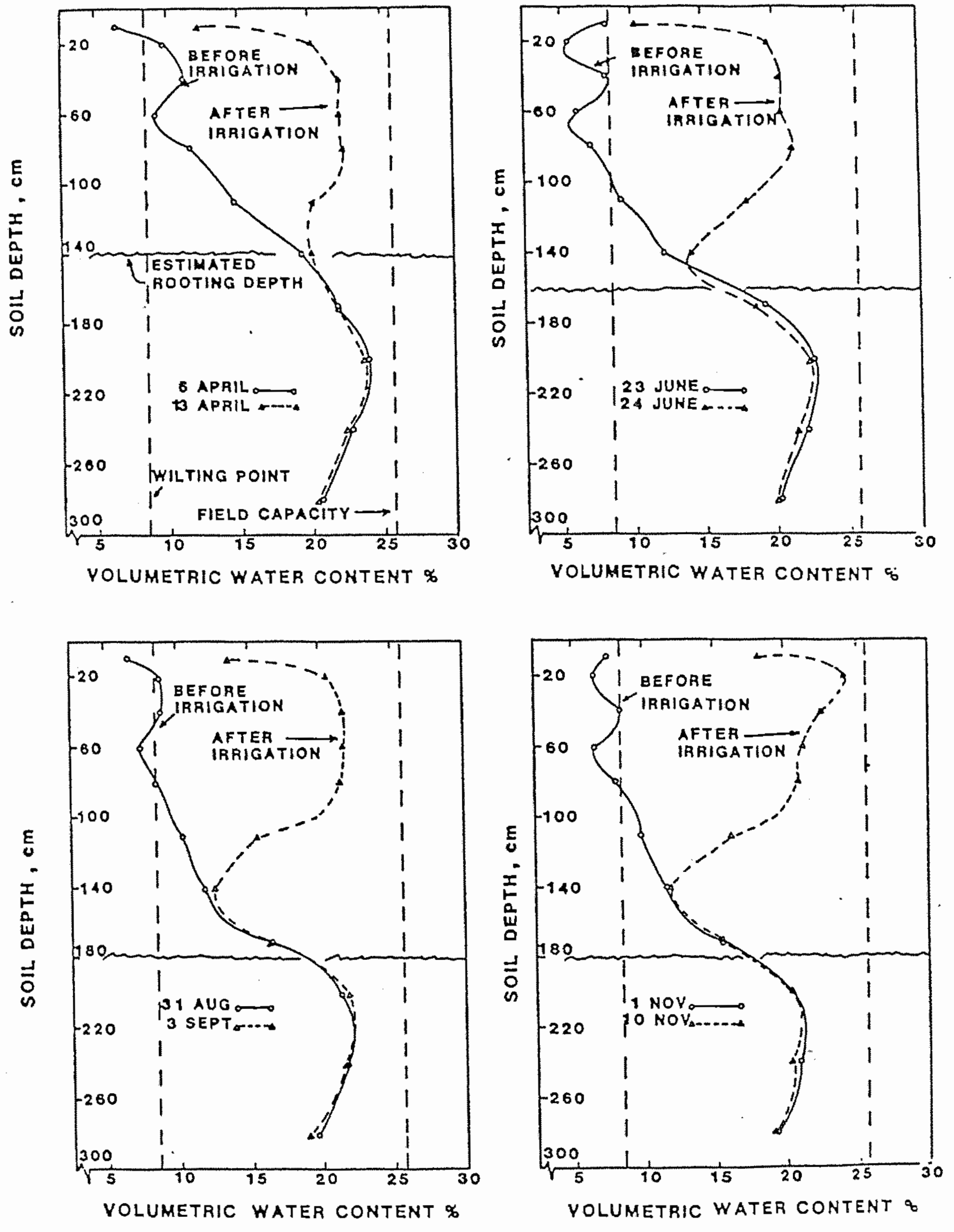


Figure 13. Soil water content profiles and estimated plant rooting depths for selected dates with the I_3 irrigation treatment at Mesa, Arizona, 1982.

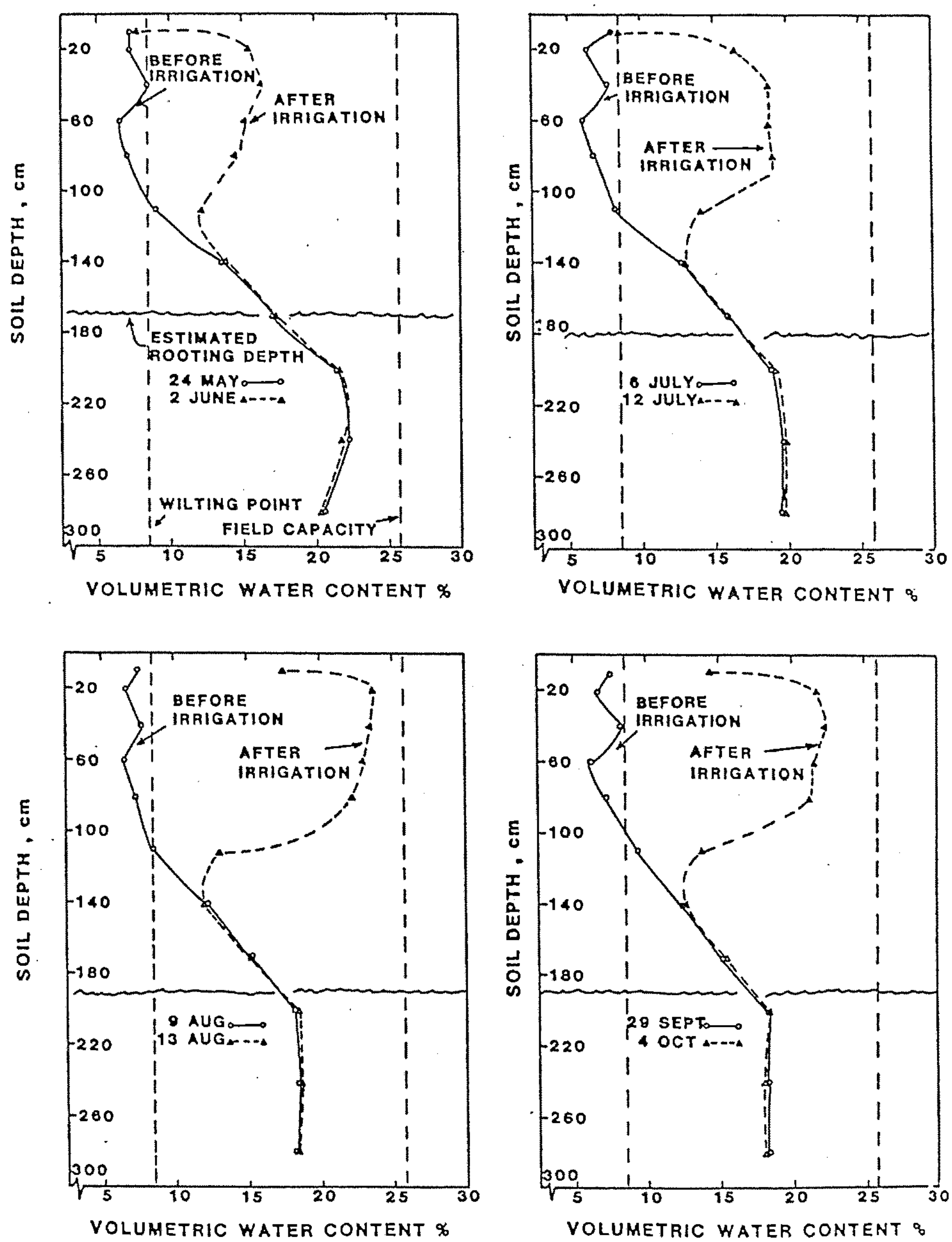


Figure 14. Soil water content profiles and estimated plant rooting depths for selected dates with the I_4 irrigation treatment at Mesa, Arizona, 1982.

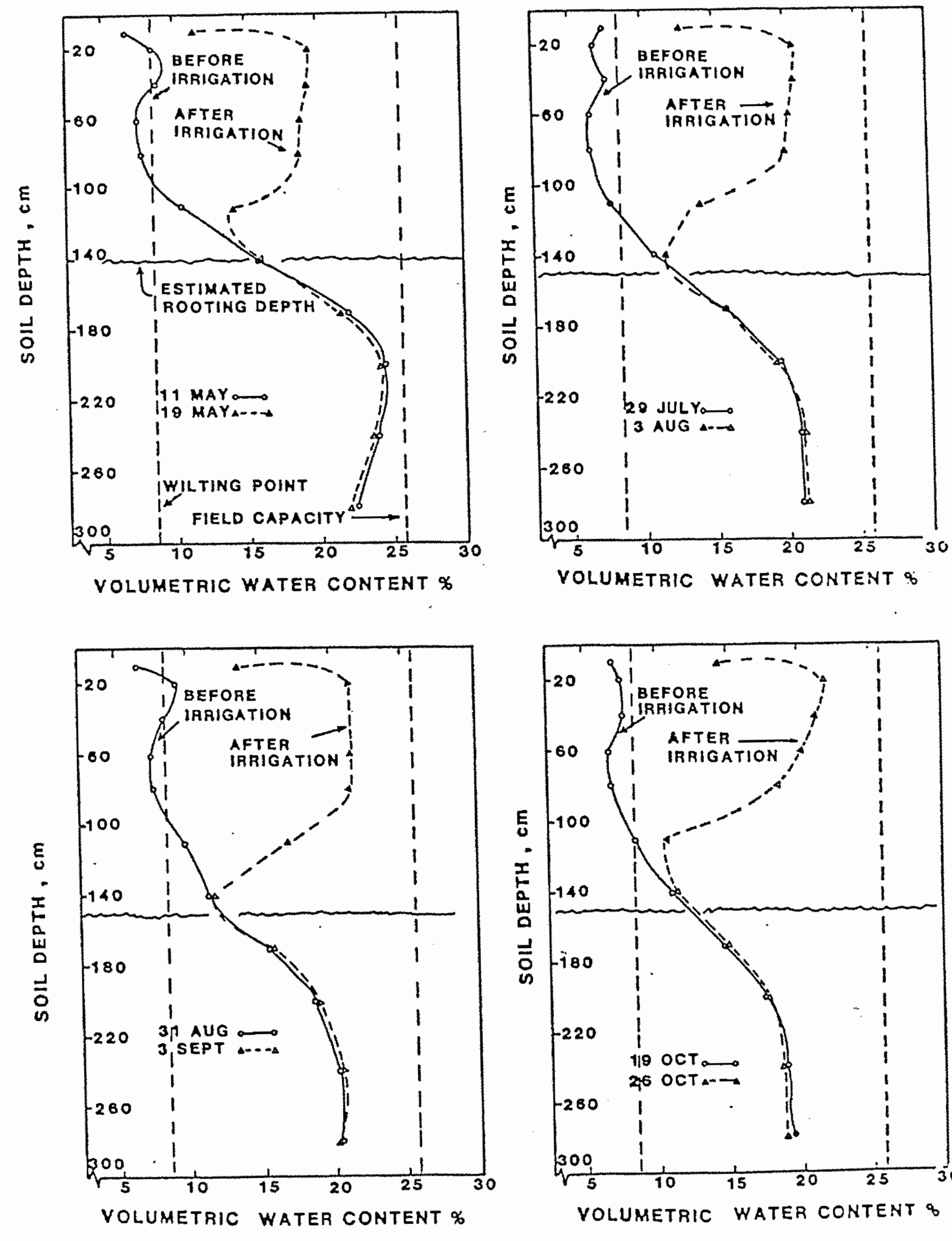


Figure 15. Soil water content profiles and estimated plant rooting depths for selected dates with the I5 irrigation treatment at Mesa, Arizona, 1982.

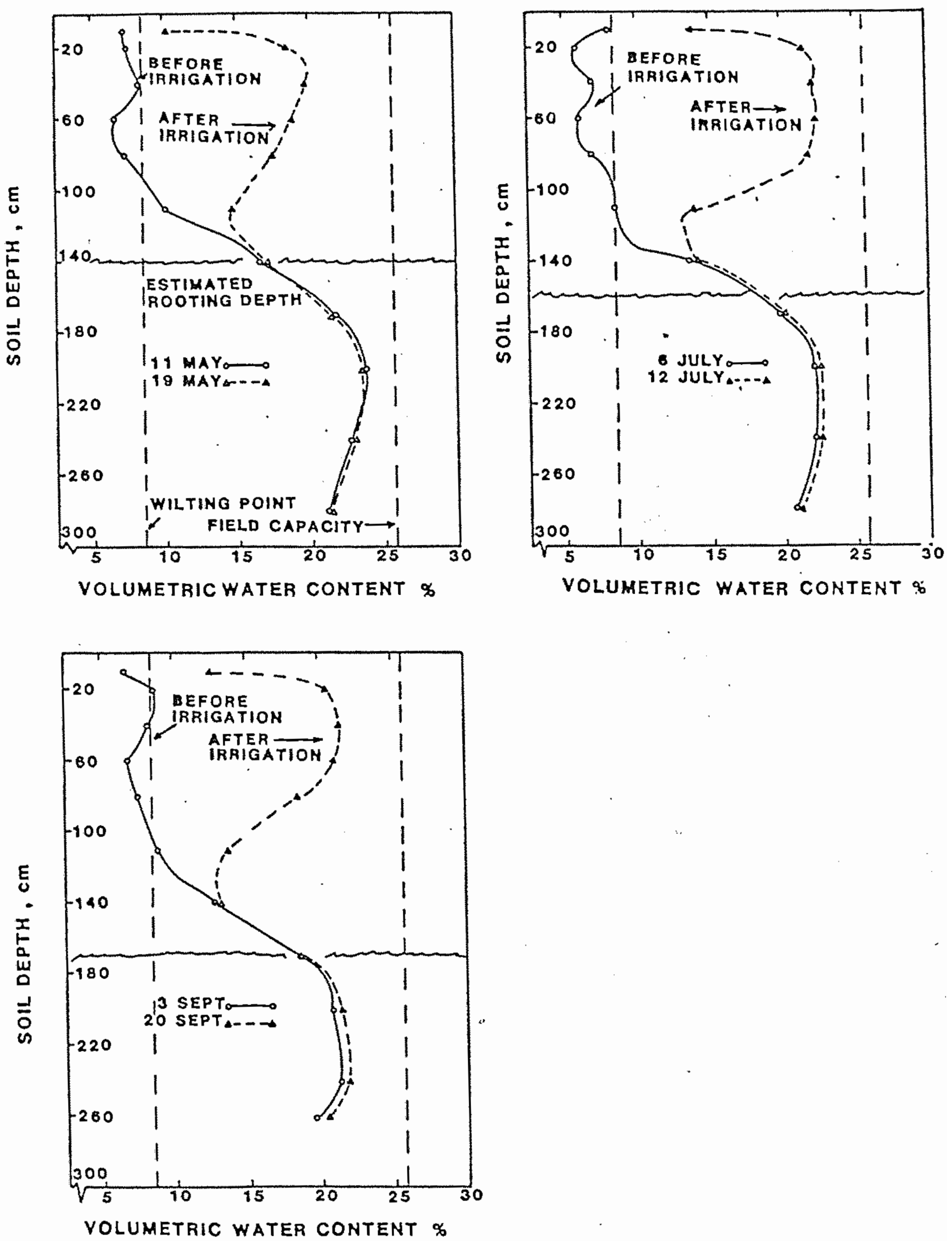


Figure 16. Soil water content profiles and estimated plant rooting depths for selected dates with the I_6 irrigation treatment at Mesa, Arizona, 1982.

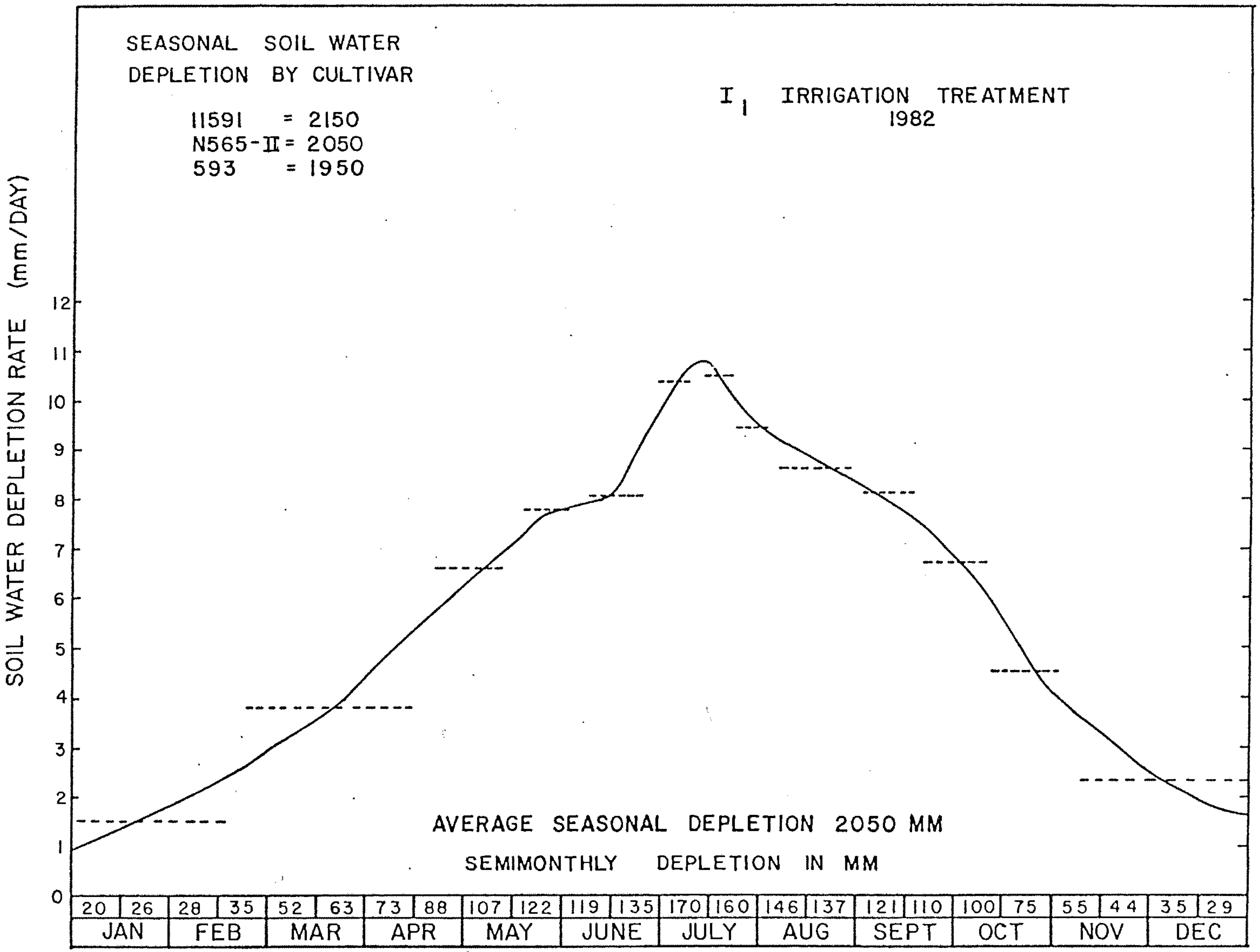


Figure 17. Measured soil water depletion for the I_1 irrigation treatment a… esa, …izo…, 198… (Tw… i…gati… wer… …pli… afte…
69% of available soil water was depleted in the 0-180-cm

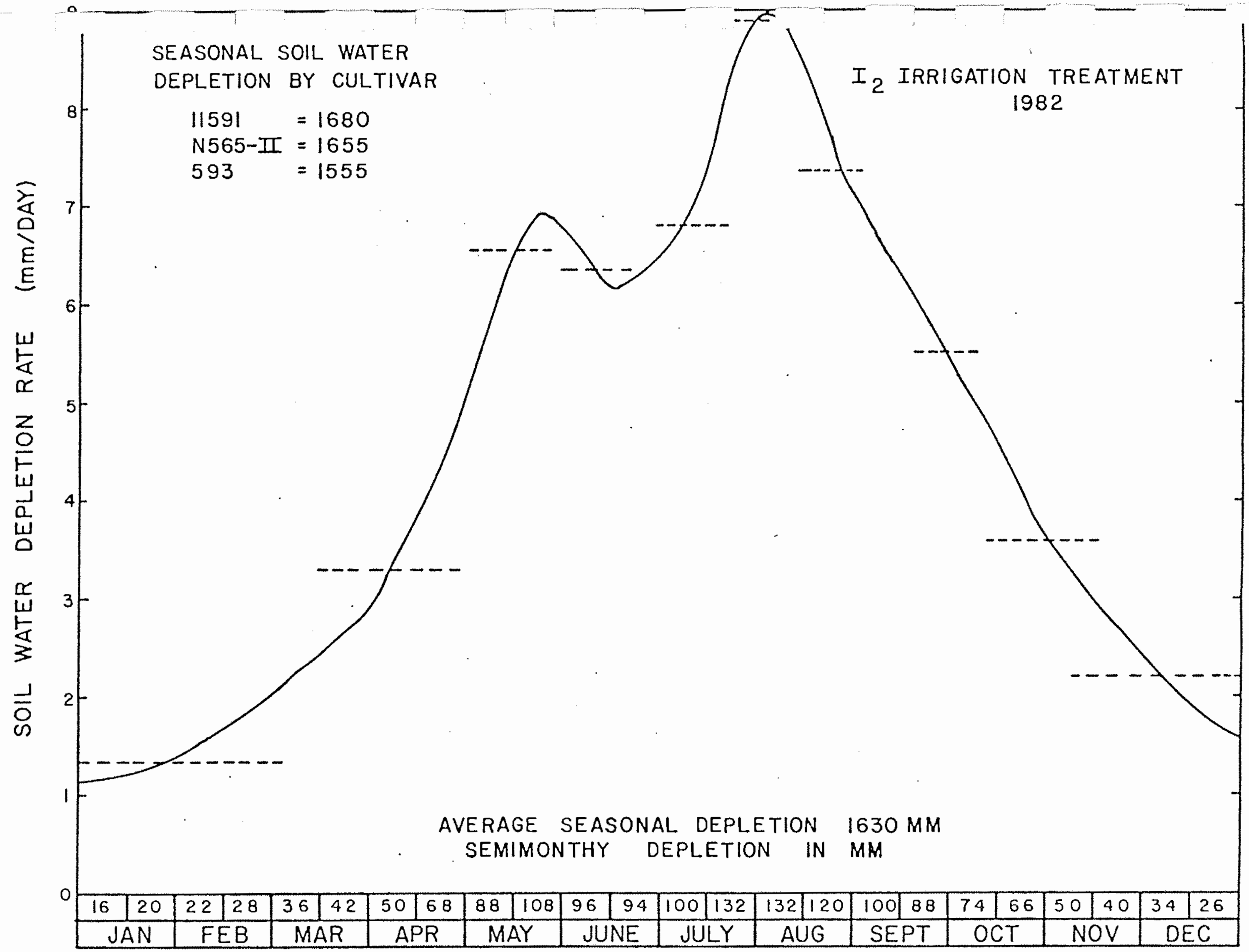
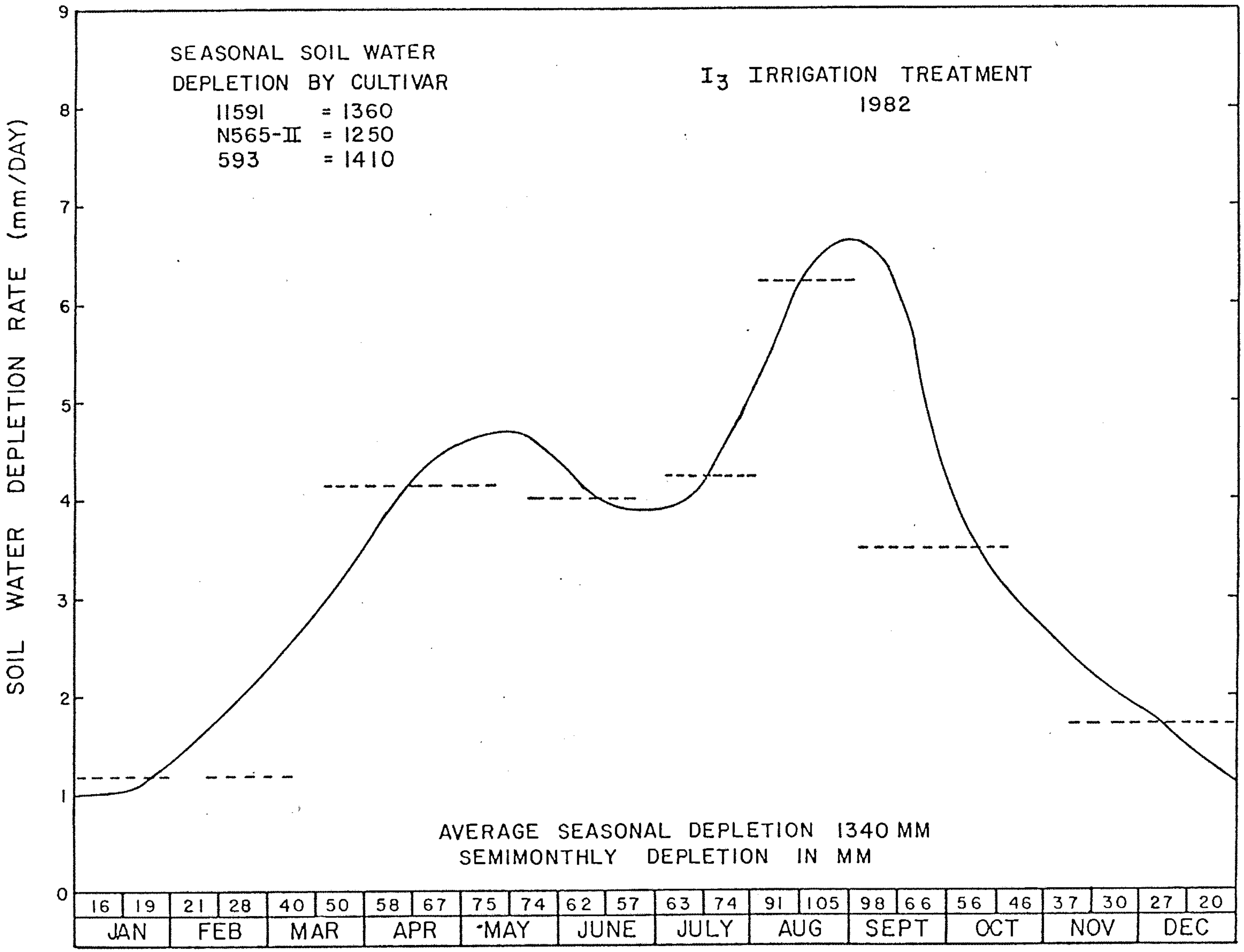


Figure 18. Measured soil water depletion for the I_2 irrigation treatment at Mesa, Arizona, 1982. (Nine irrigations were applied after 82% of available soil water was depleted in the 0-180-cm depth).


SEASONAL SOIL WATER
DEPLETION BY CULTIVAR
11591 = 1360
N565-II = 1250
593 = 1410
I3 IRRIGATION TREATMENT
1982
SOIL WATER DEPLETION RATE (mm/DAY)
AVERAGE SEASONAL DEPLETION 1340 MM
SEMIMONTHLY DEPLETION IN MM
16 19 21 28 40 50 58 67 75 74 62 57 63 74 91 105 98 66 56 46 37 30 27 20
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
0 1 2 3 4 5 6 7 8 9

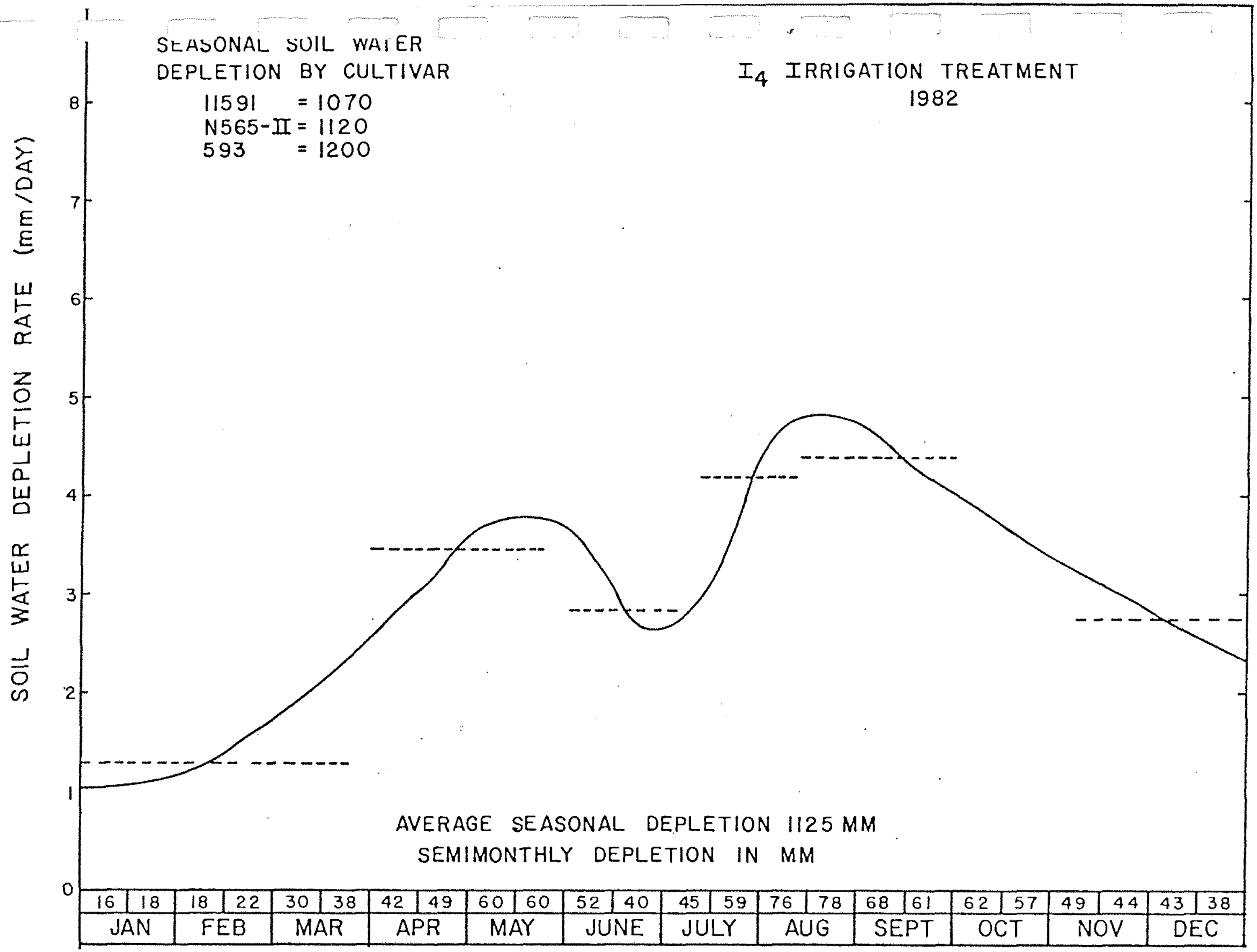


Figure 20. Measured soil water depletion for the I_4 irrigation treatment at Mesa, Arizona, 1982. (Five irrigations were applied after 90% of available soil water was depleted in the 0-180-cm depth).

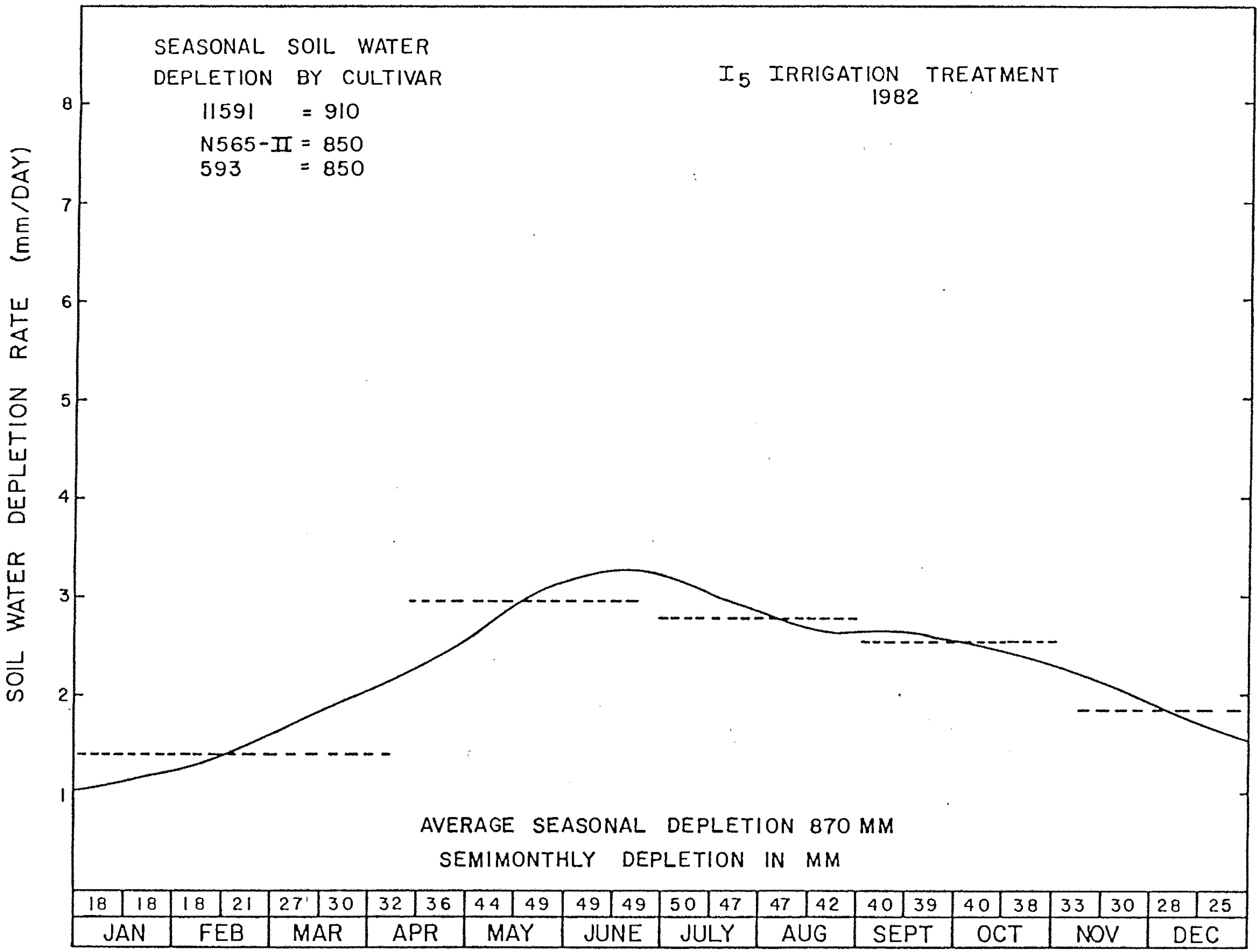


Figure 21. Measured soil water depletion for the I_5 irrigation treatment at Mesa, Arizona. 1982. (Four irrigations were [illegible] 87% of available soil water was depleted in the 0-[illegible]-cm depth)

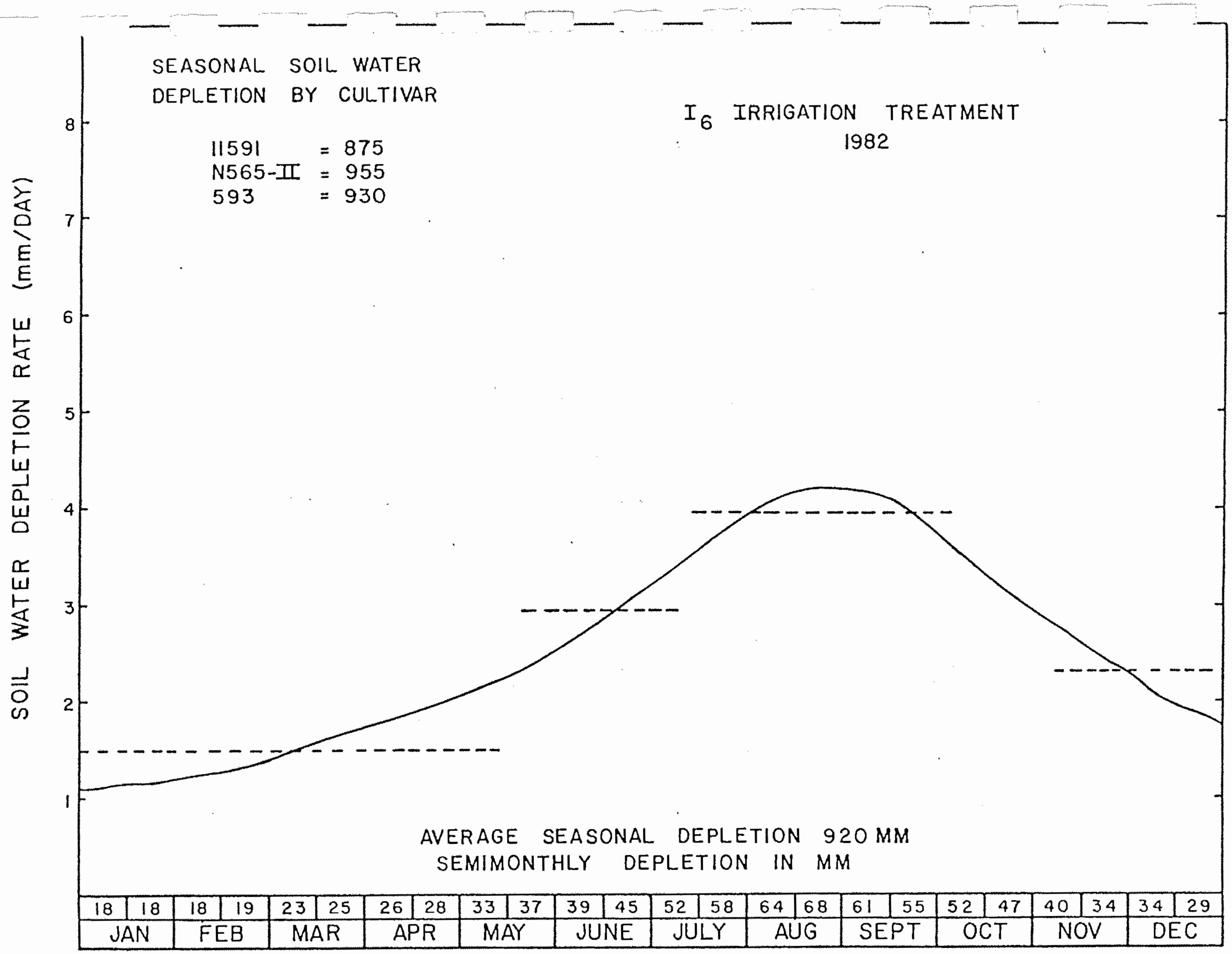


Figure 22. Measured soil water depletion for the I_6 irrigation treatment at Mesa, Arizona, 1982. (Three irrigations were applied after 90% of available soil water was depleted in the 0-180-cm depth).

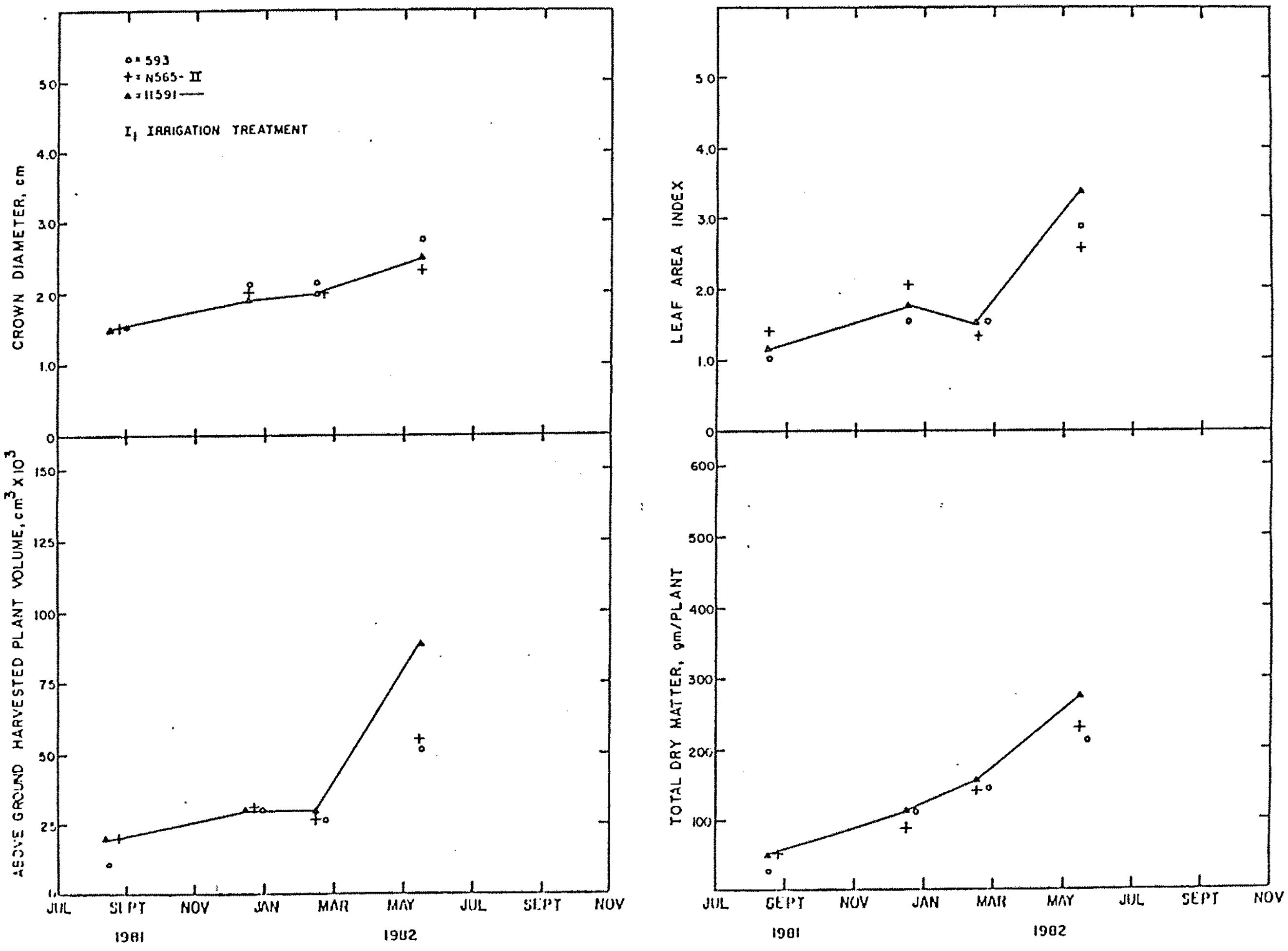


Figure 23. Crown diameter, plant volume, leaf area index, and dry matter production for periodic guayule harvests of the I1 irrigation treatment and three cultivars at Mesa, Arizona, 1981-82.

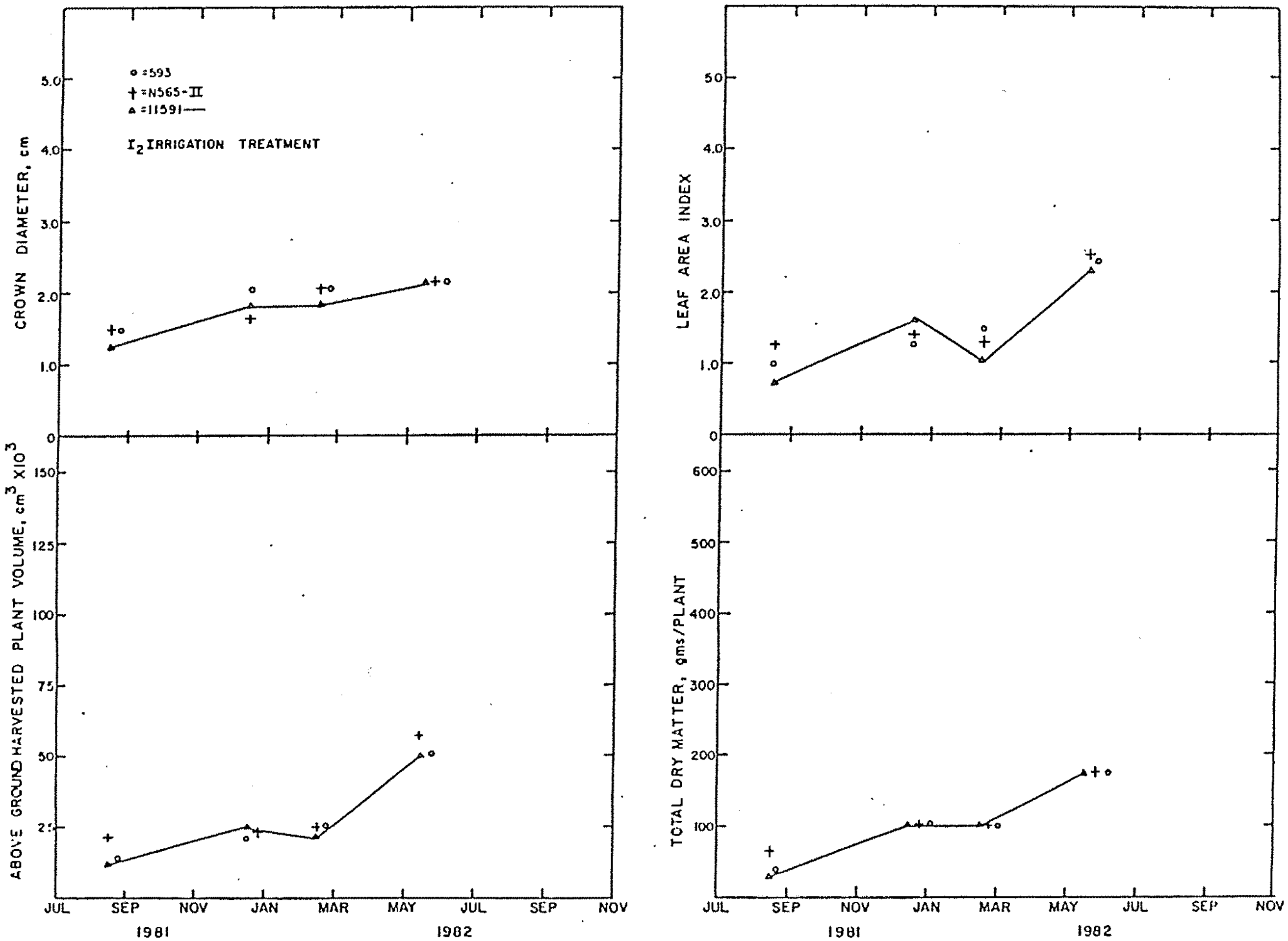


Figure 24. Crown diameter, plant volume, leaf area index, and dry matter production for periodic guayule harvests of the I_2 irrigation treatment and three cultivars at Mesa, Arizona, 1981-82.

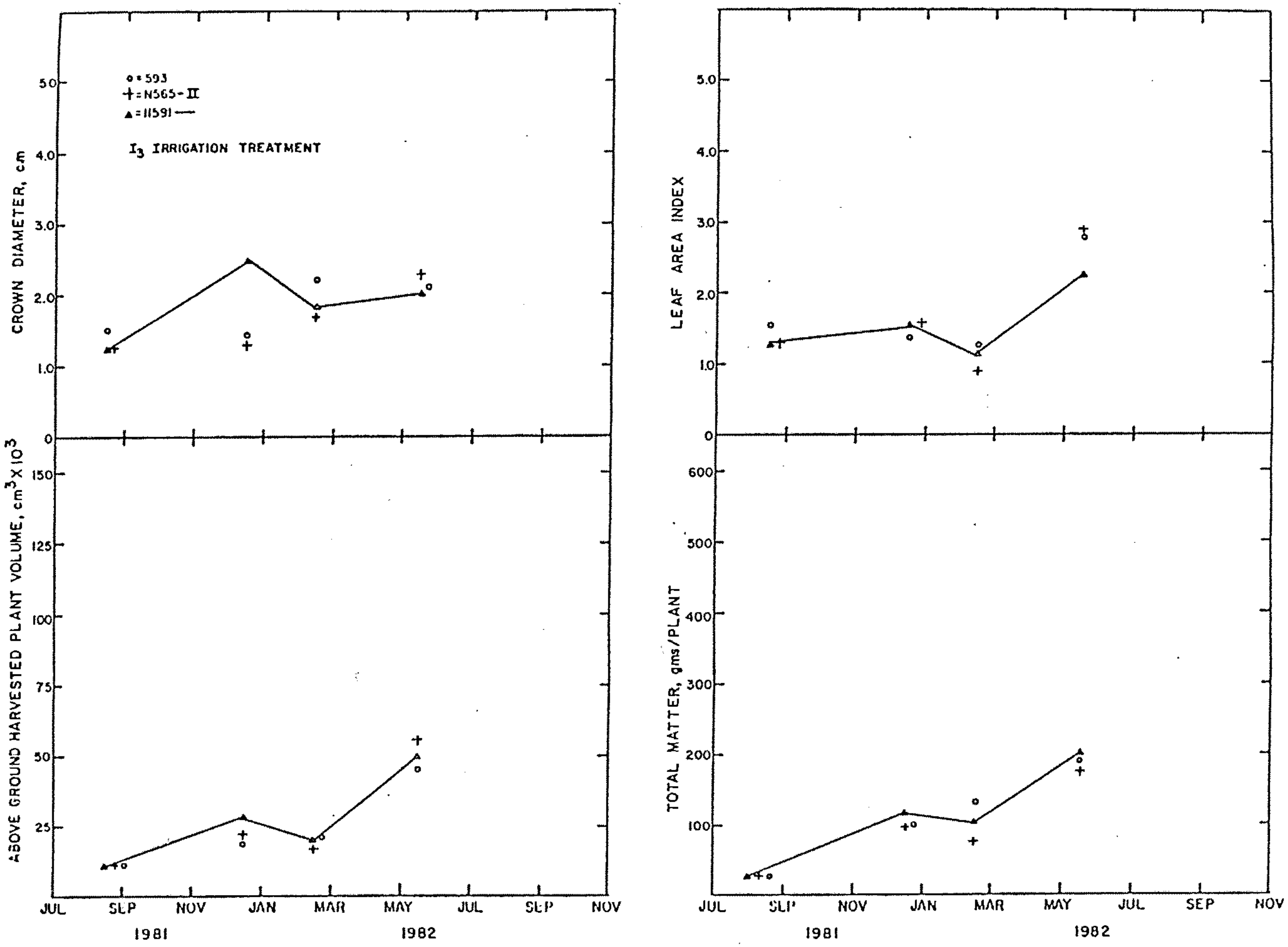


Figure 25. Crown diameter, plant volume, leaf area index, and dry matter

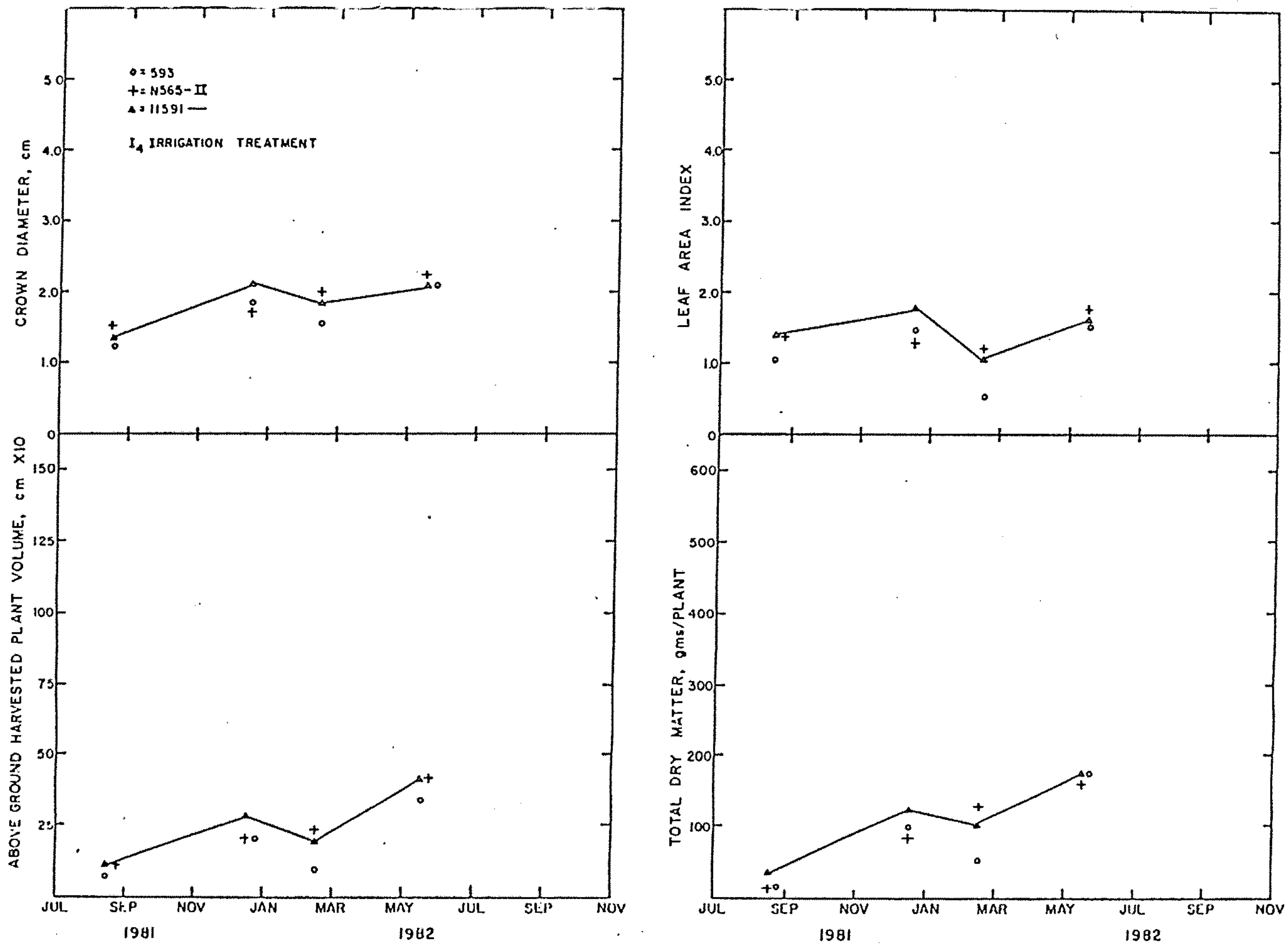


Figure 26. Crown diameter, plant volume, leaf area index, and dry matter production for periodic guayule harvests of the I_4 irrigation treatment and three cultivars at Mesa, Arizona, 1981-82.

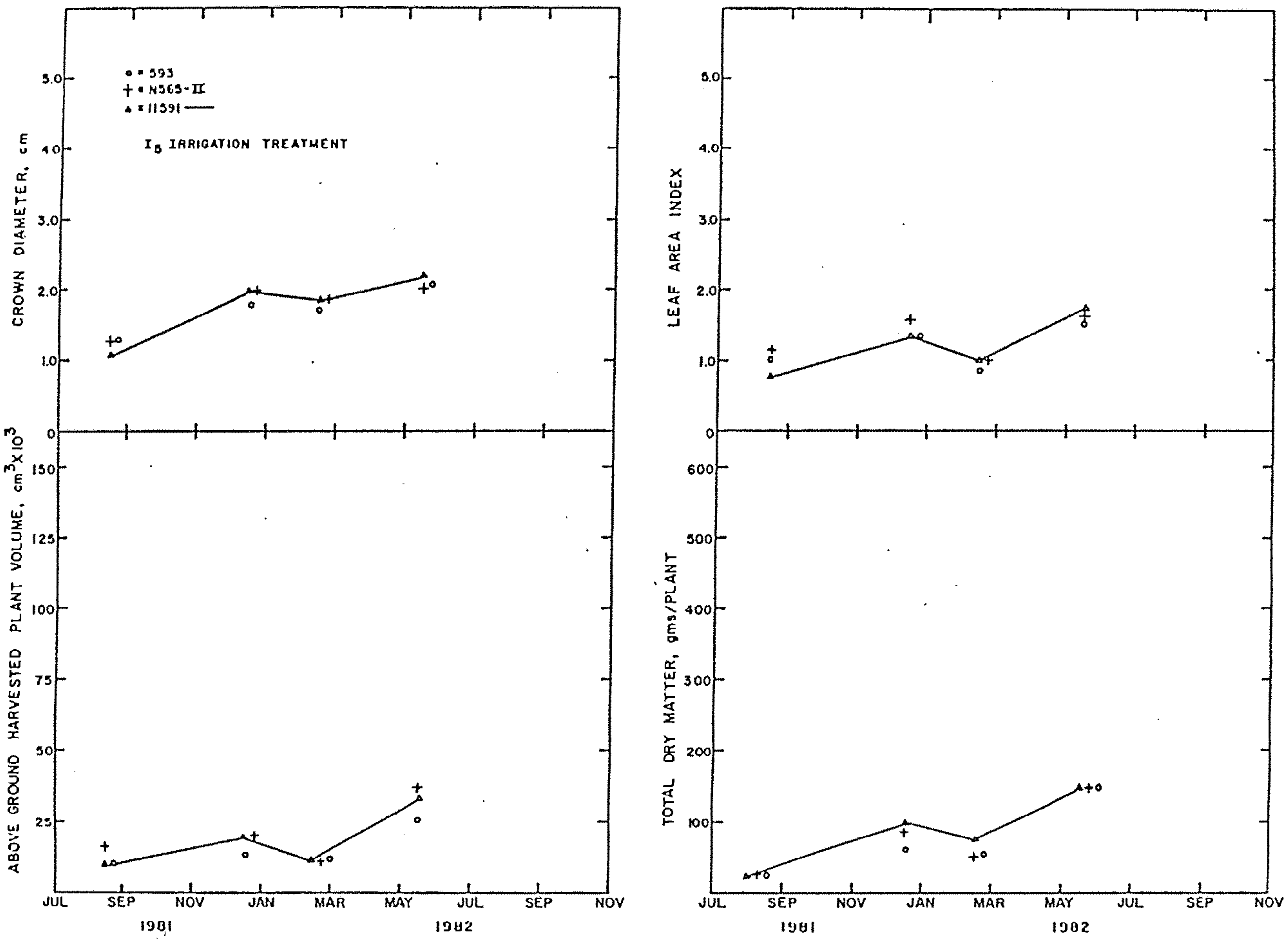


Figure 27. Crown diameter, plant volume, leaf area index, and dry matter production for periodic guayule harvests of the I_5 irrigation treatment and three cultivars at Mesa, Arizona, 1981-82.

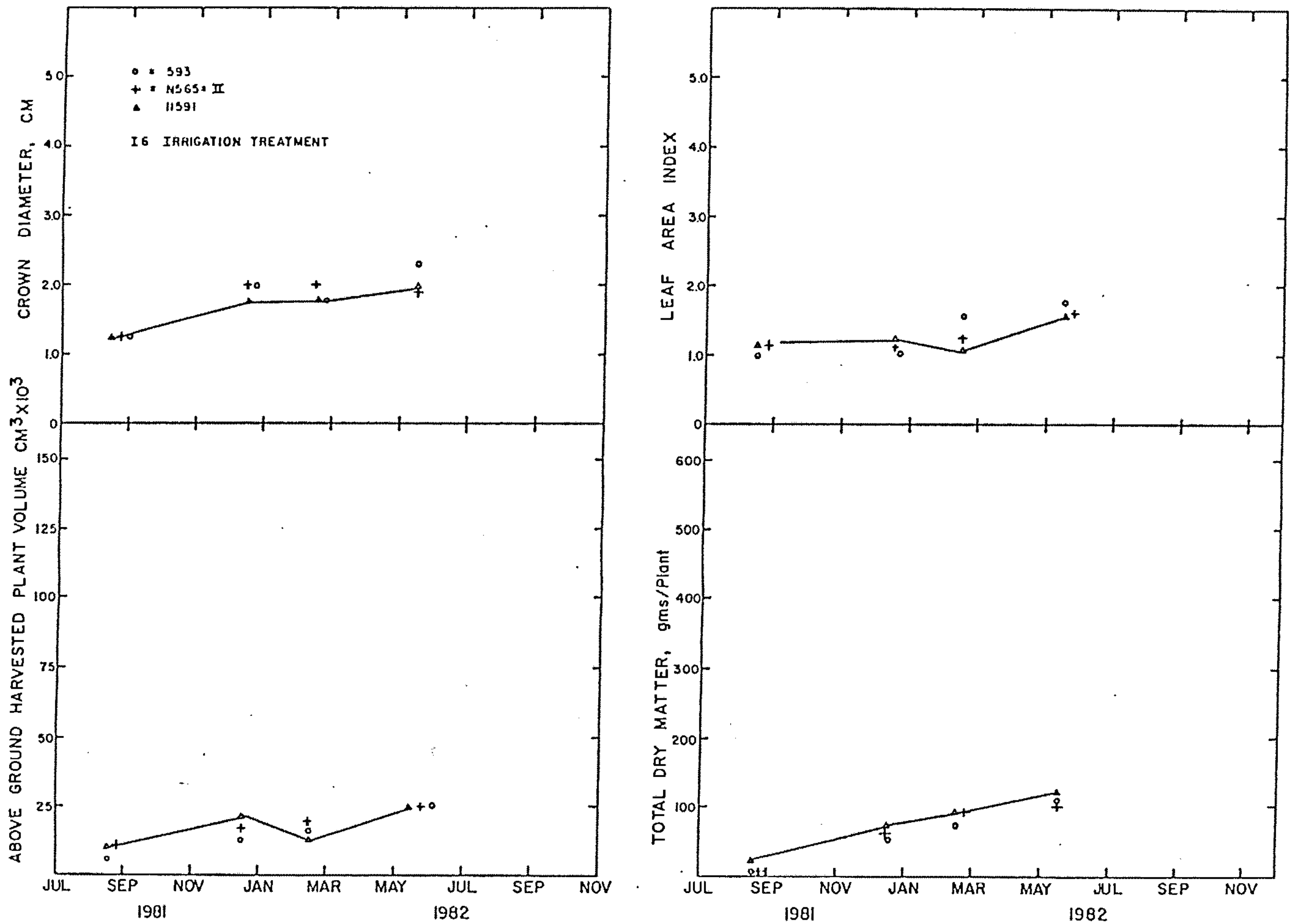


Figure 28. Crown diameter, plant volume, leaf area index, and dry matter production for periodic guayule harvests of the I_6 irrigation treatment and three cultivars at Mesa, Arizona, 1981-82.

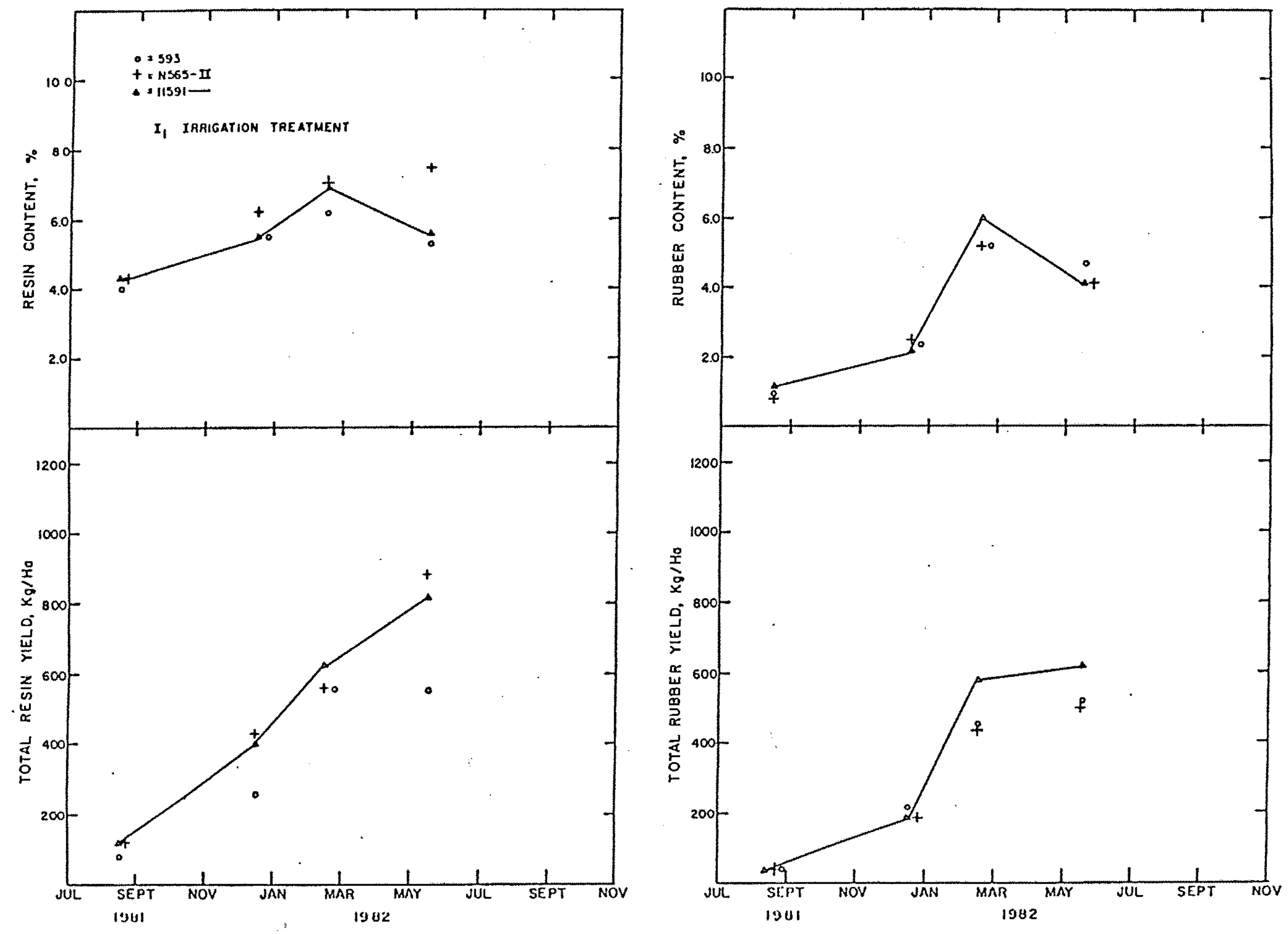


Figure 29. Resin and rubber contents and yield for periodic harvests of the I_1 irrigation treatment and three cultivars at Mesa, Arizona, 1981-82.

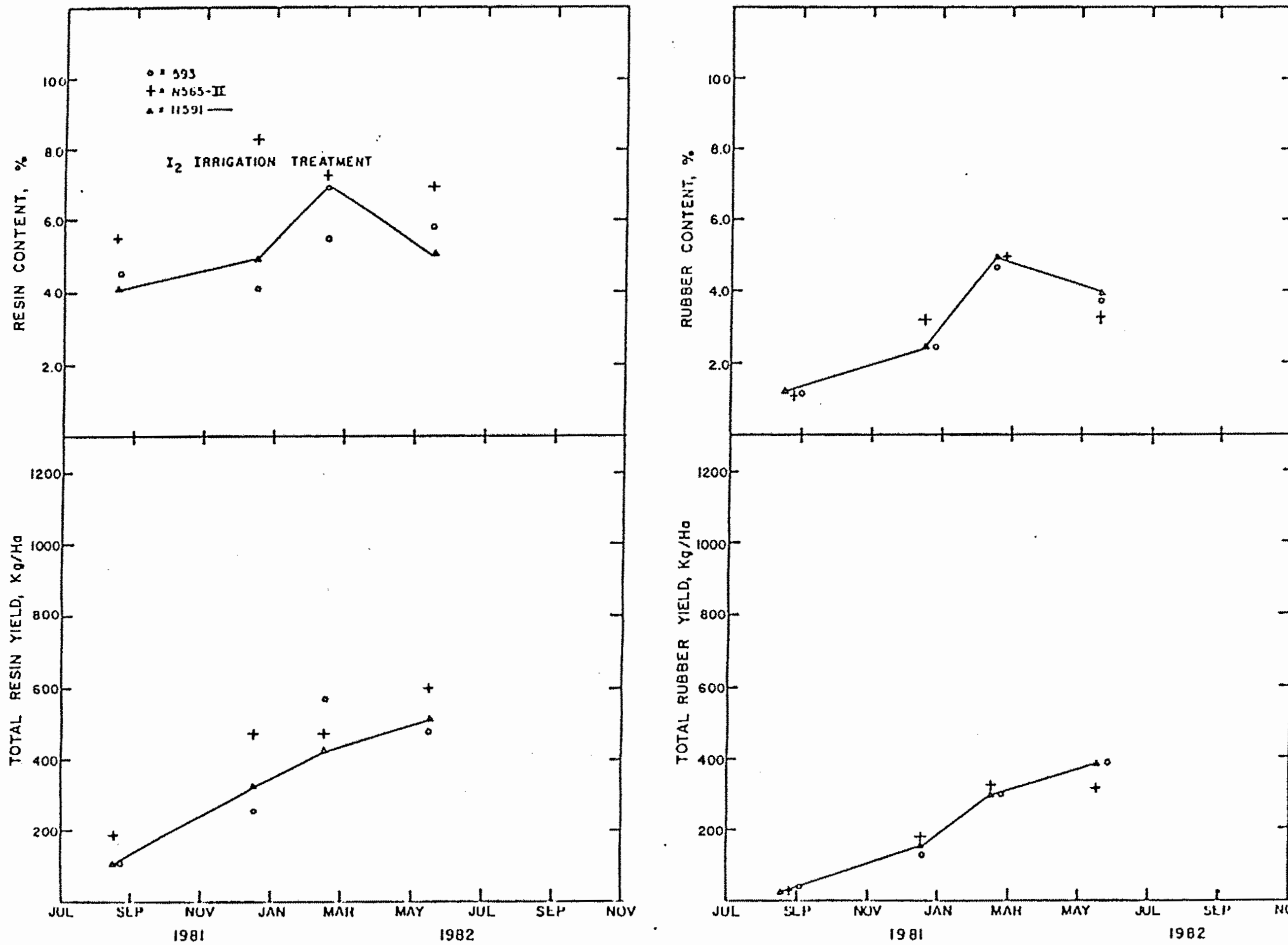


Figure 30. Resin and rubber contents and yield for periodic harvests of the I_2 irrigation treatment and three cultivars at Mesa, Arizona, 1981-82.

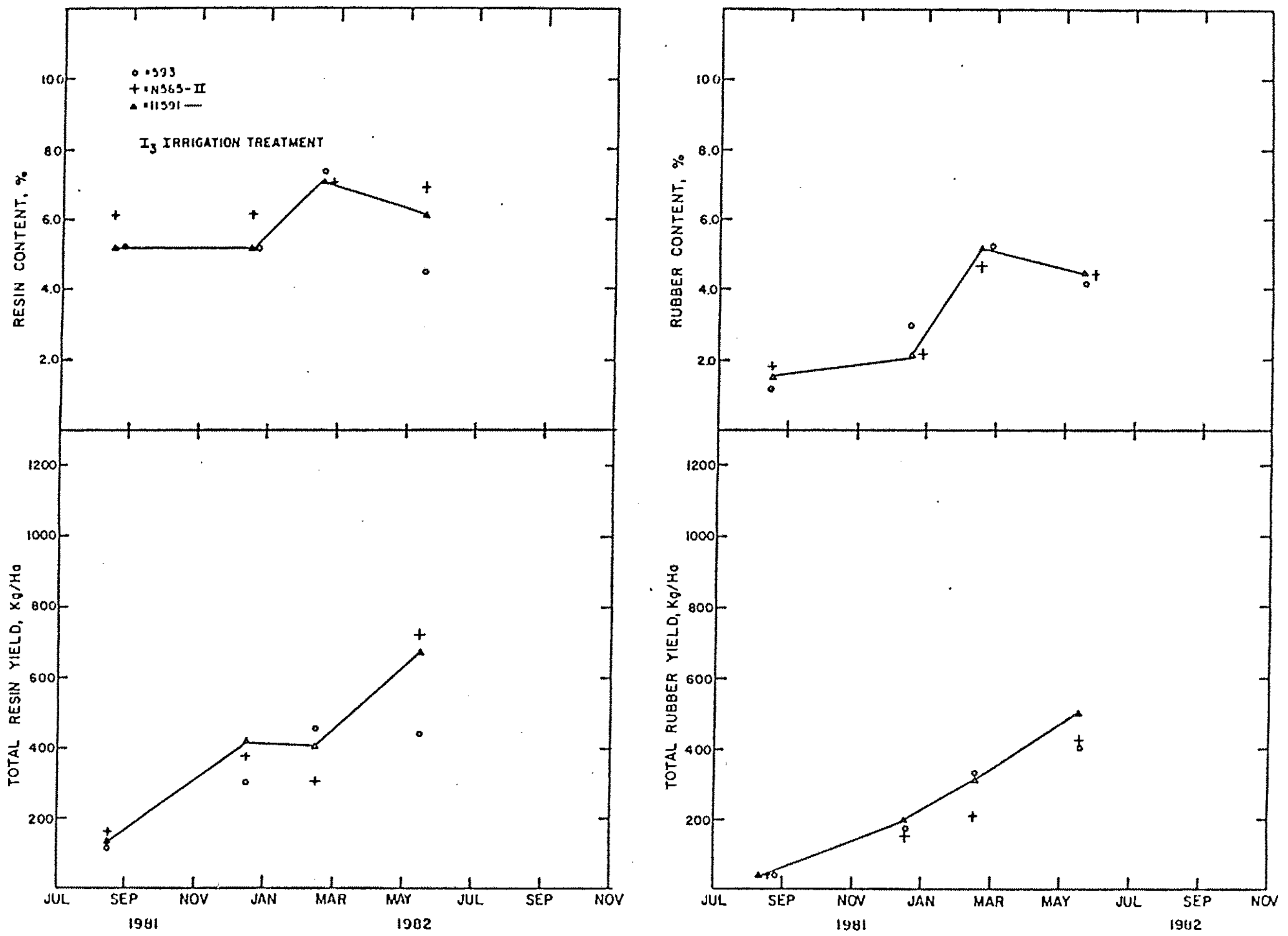


Figure 31. Resin and rubber contents and yield for periodic harvests of the I[illegible] irr[illegible]ion [illegible]atm[illegible] and [illegible]ree [illegible]tiv[illegible] at [illegible], Arizona, 1981-82.

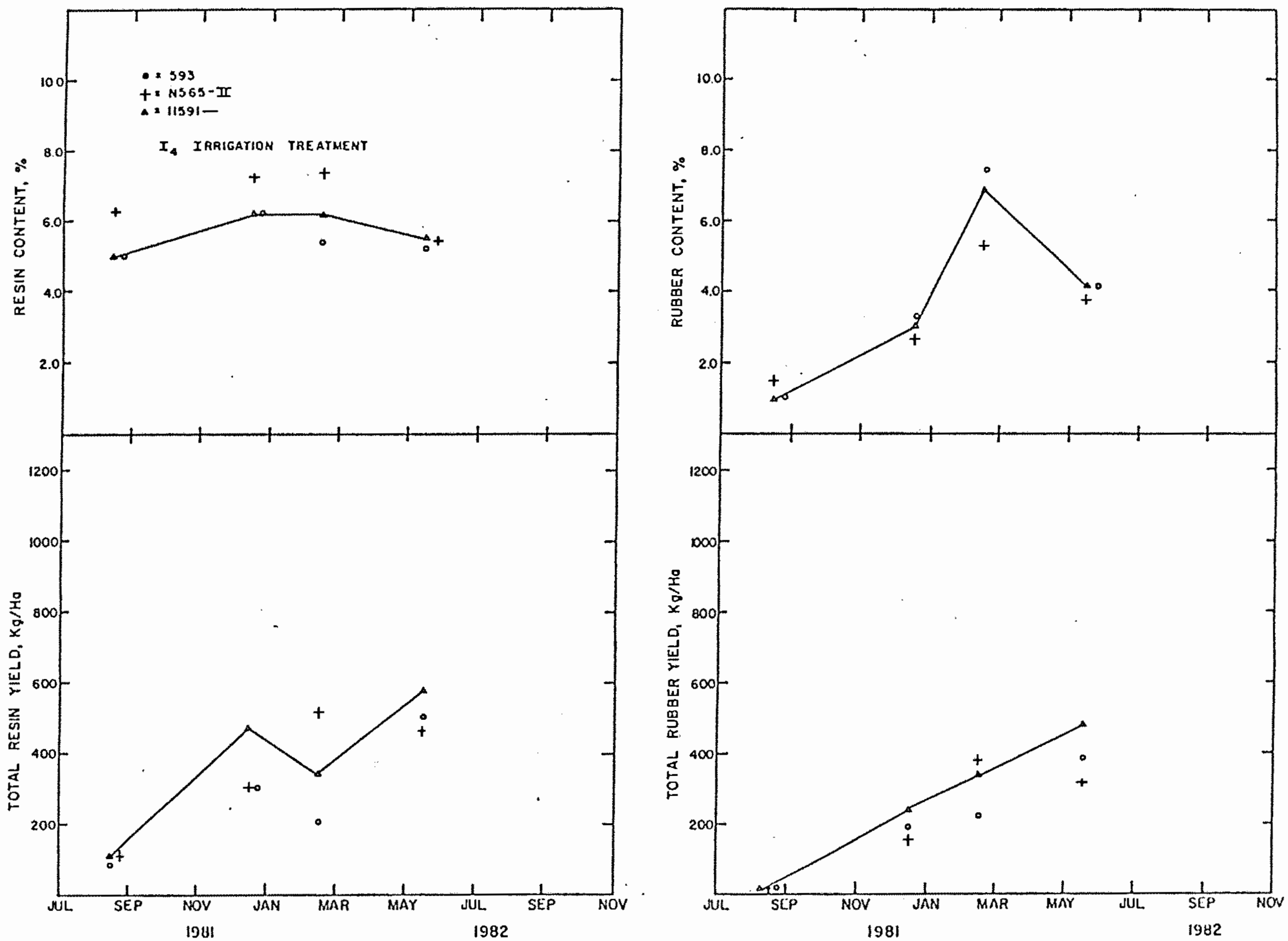


Figure 32. Resin and rubber contents and yield for periodic harvests of the I_4 irrigation treatment and three cultivars at Mesa, Arizona, 1981-82.

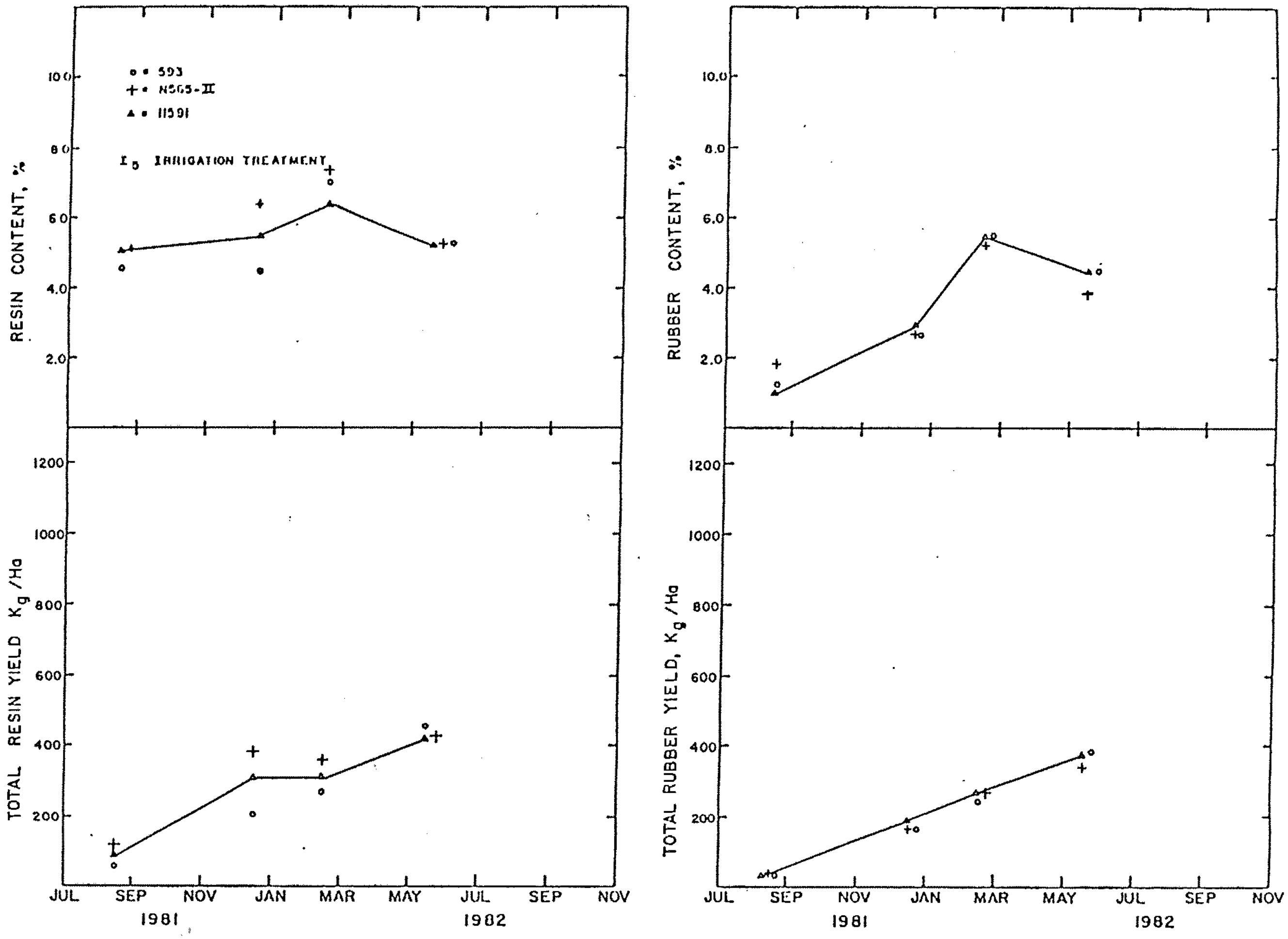


Figure 33. Resin and rubber contents and yield for periodic harvests of the I5 irrigation treatment and three cultivars at Mesa, Arizona, 1981-82.

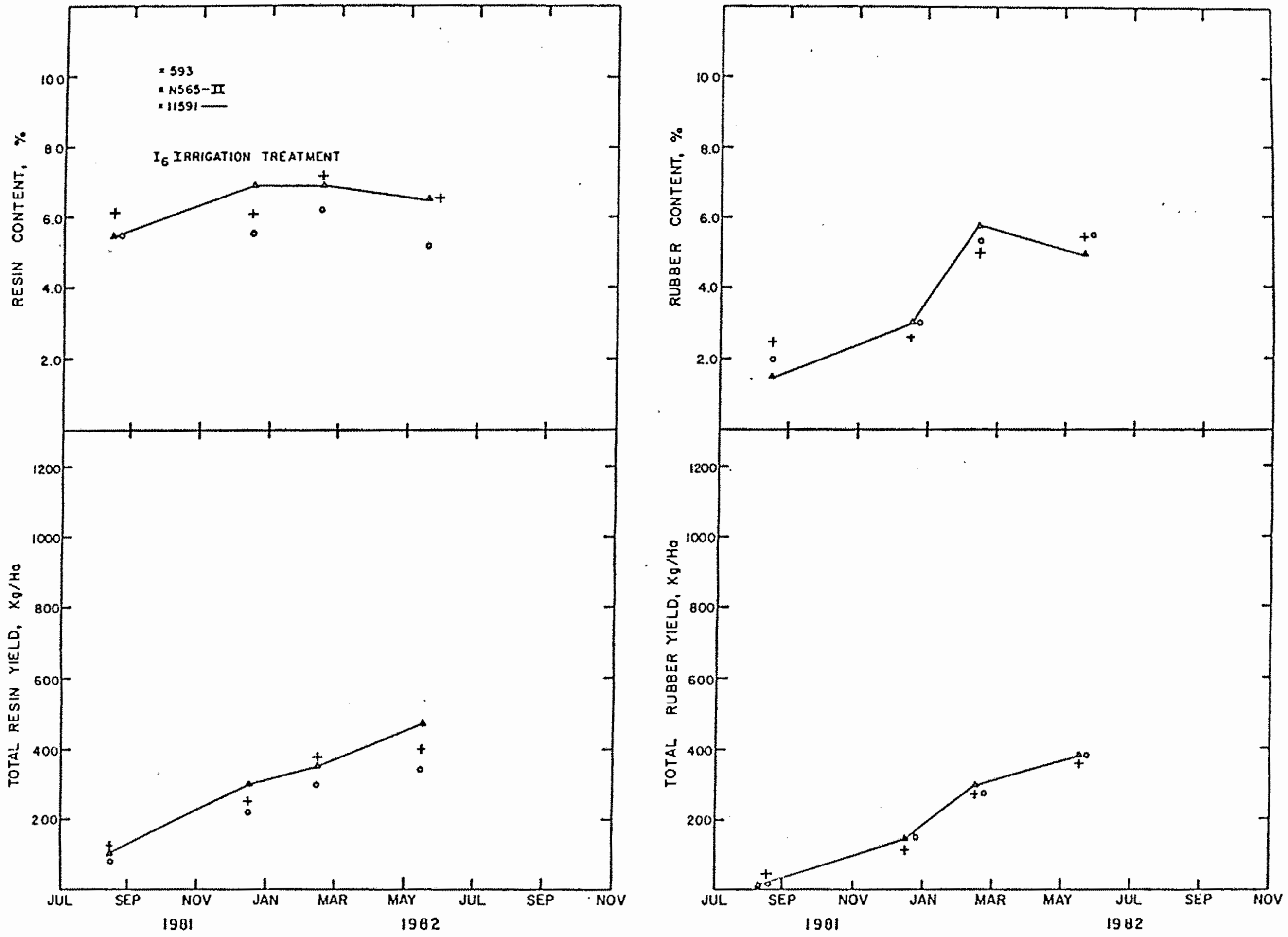


Figure 34. Resin and rubber contents and yield for periodic harvests of the I_6 irrigation treatment and three cultivars at Mesa, Arizona, 1981-82.

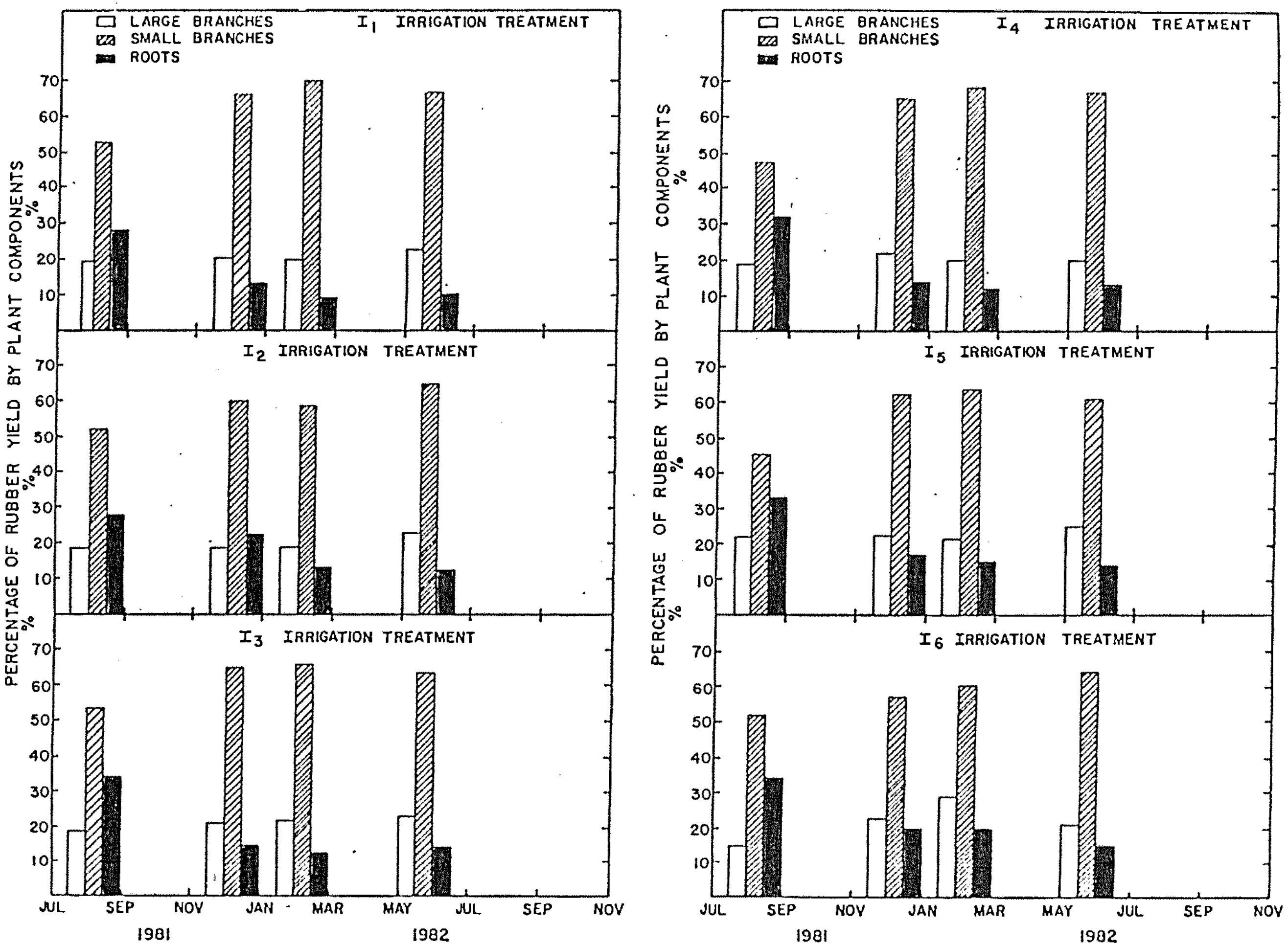


Figure 35. Percentage of resin yield from large branches, small branches and roots at periodic harvests for the six irrigation treat-ments at Mesa, Arizona, 1981-82.

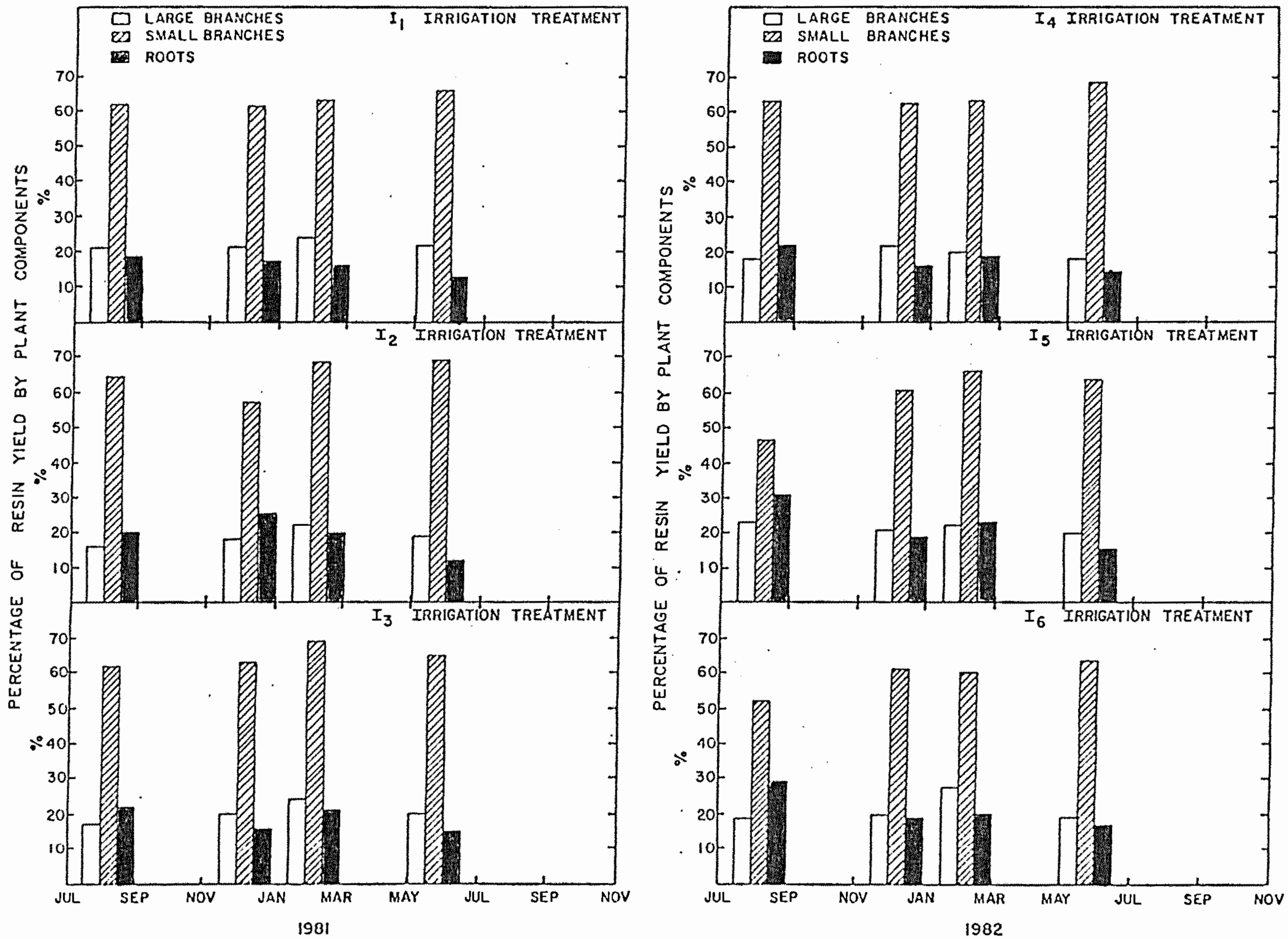


Figure 36. Percentage of rubber yield from large branches, small branches, and roots for periodic harvests on the six irrigation treatments at Mesa, Arizona, 1981-82.

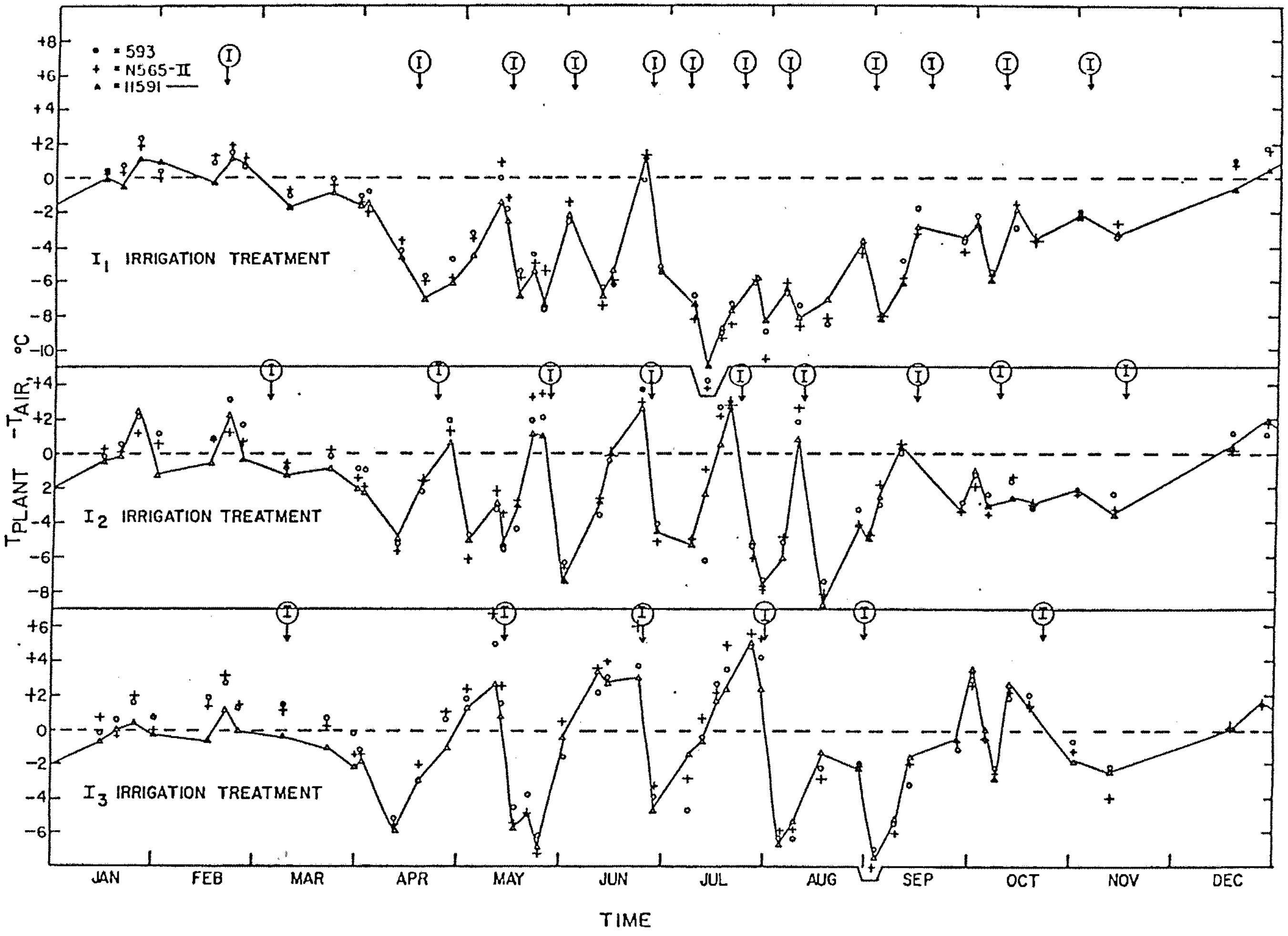


Figure 37. Plant-air temperature differences versus time ... I_2, and I_3 irrigation treatments at Mesa, Arizona, 1982.

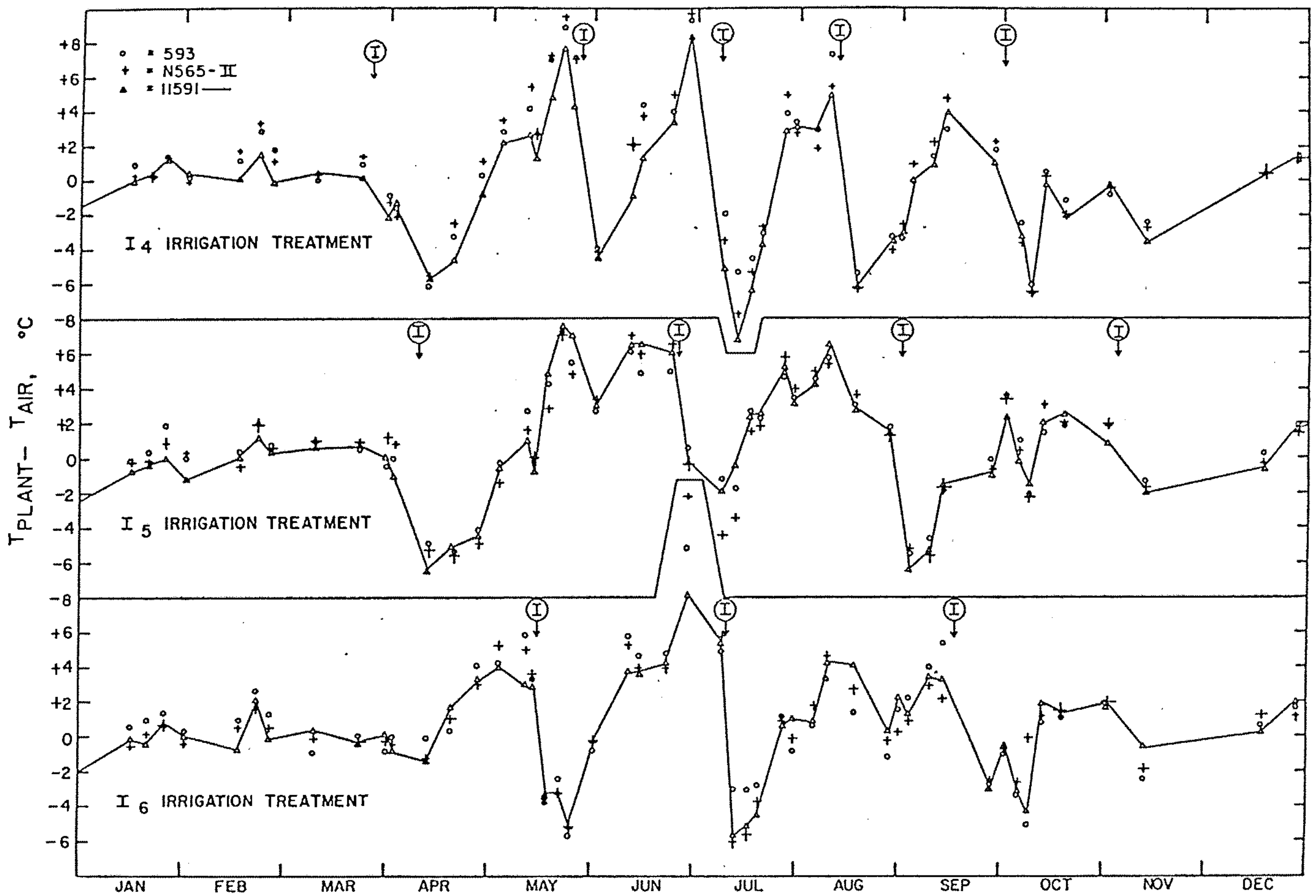


Figure 38. Plant-air temperature differences versus time under the I_4, I_5, and I_6 irrigation treatments at Mesa, Arizona, 1982.

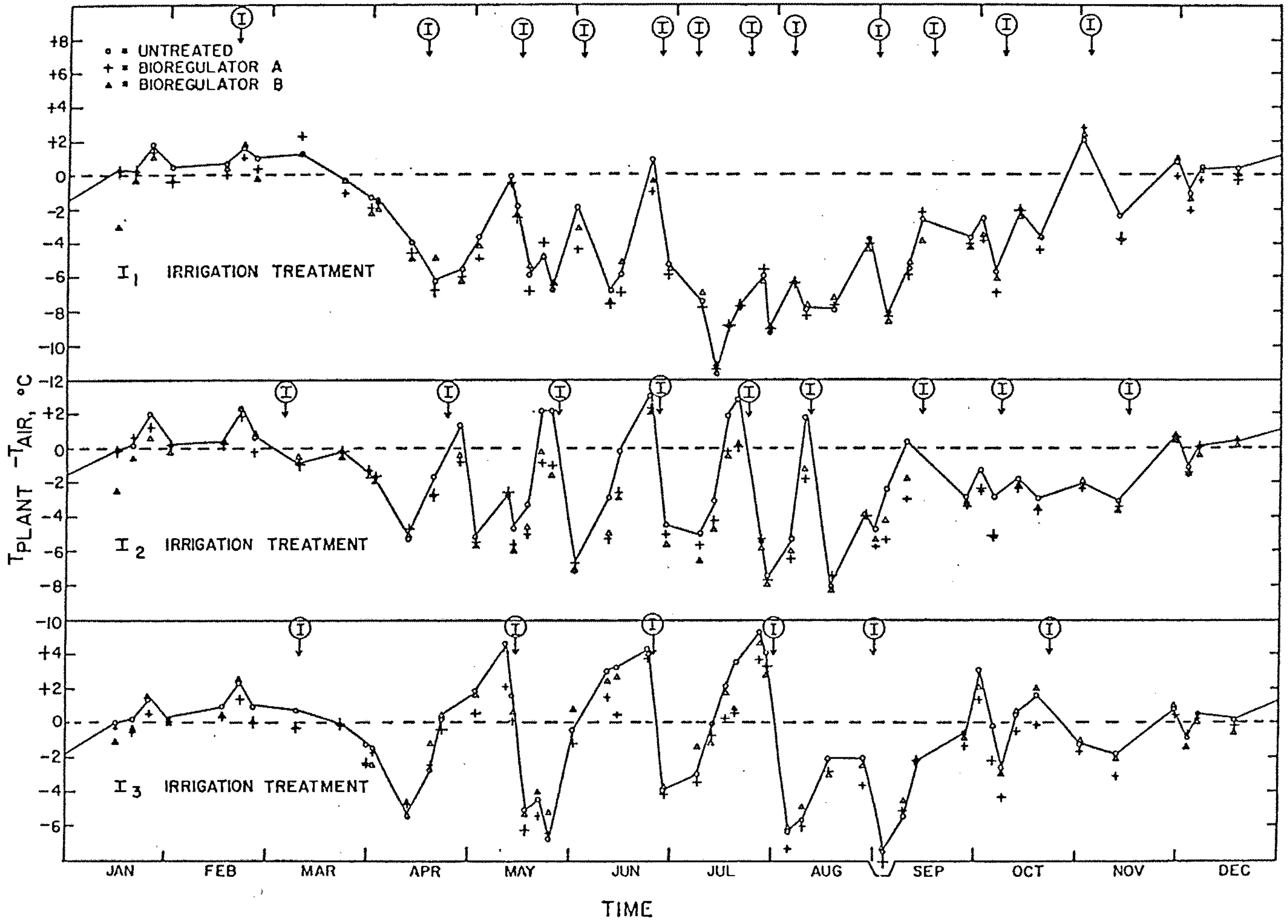


Figure 39. Average plant-air temperature differences versus time for untreated and bioregulated guayule plants under the I_1, I_2, and I_3 irrigation treatments at Mesa, Arizona, 1982.

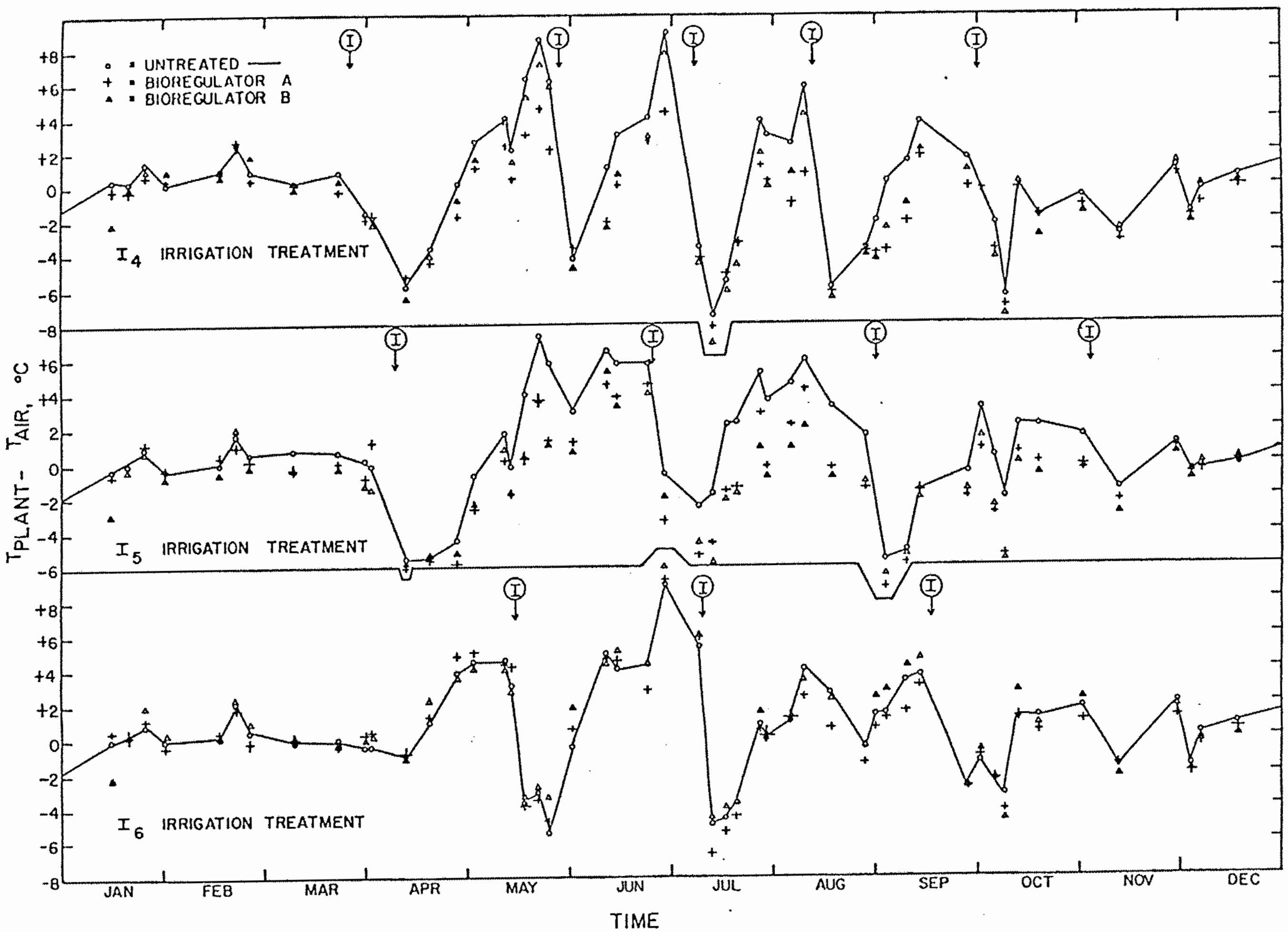


Figure 40. Average plant-air temperature differences versus time for untreated and bioregulated guayule plants under the I_4, I_5, and I_6 irrigation treatments at Mesa, Arizona, 1982.

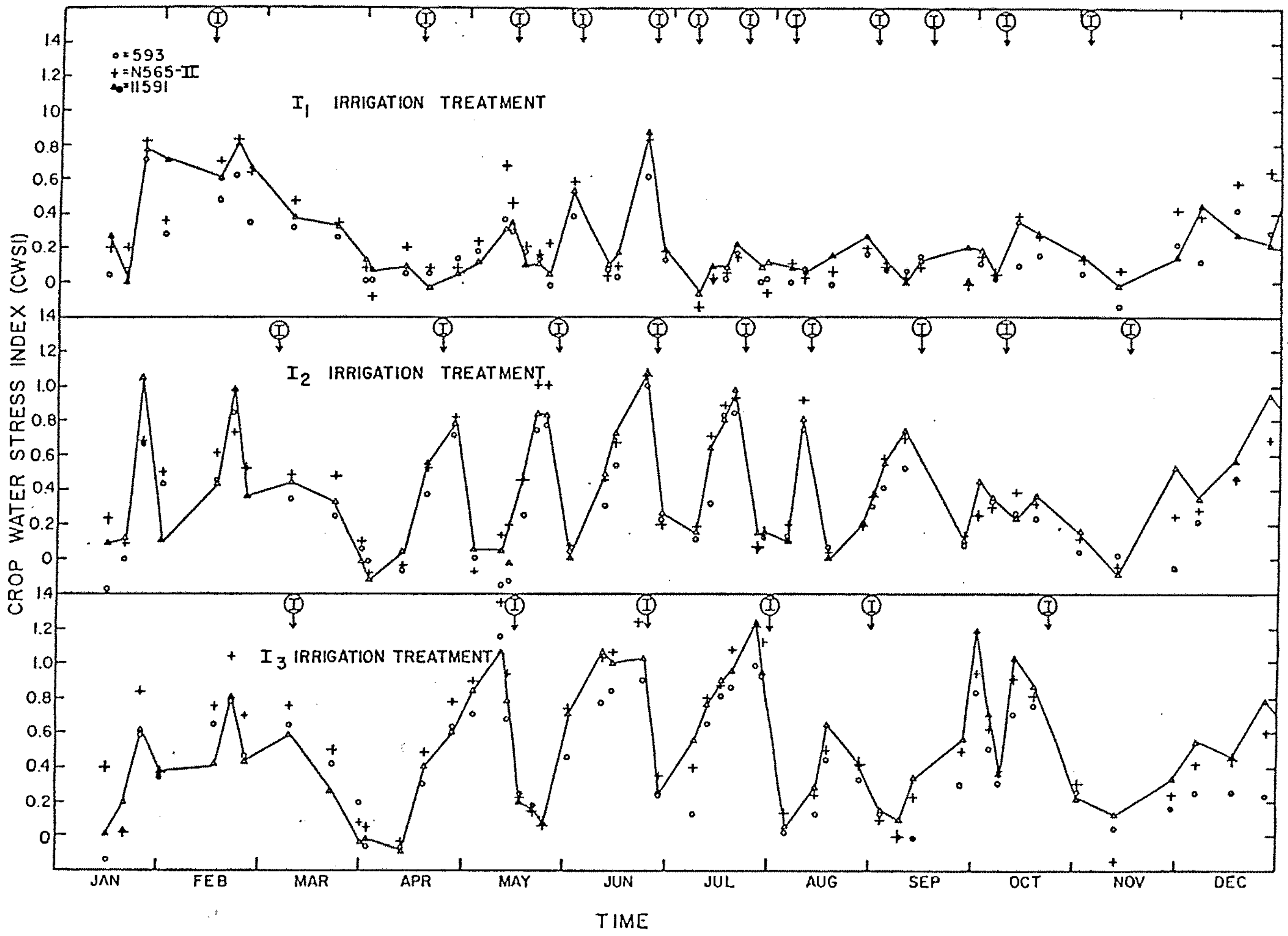


Figure 41. Crop water stress index versus time for three guayule cultivars under the I_1, I_2, and I_3 irrigation treatments at Mesa, Arizona, 1982.

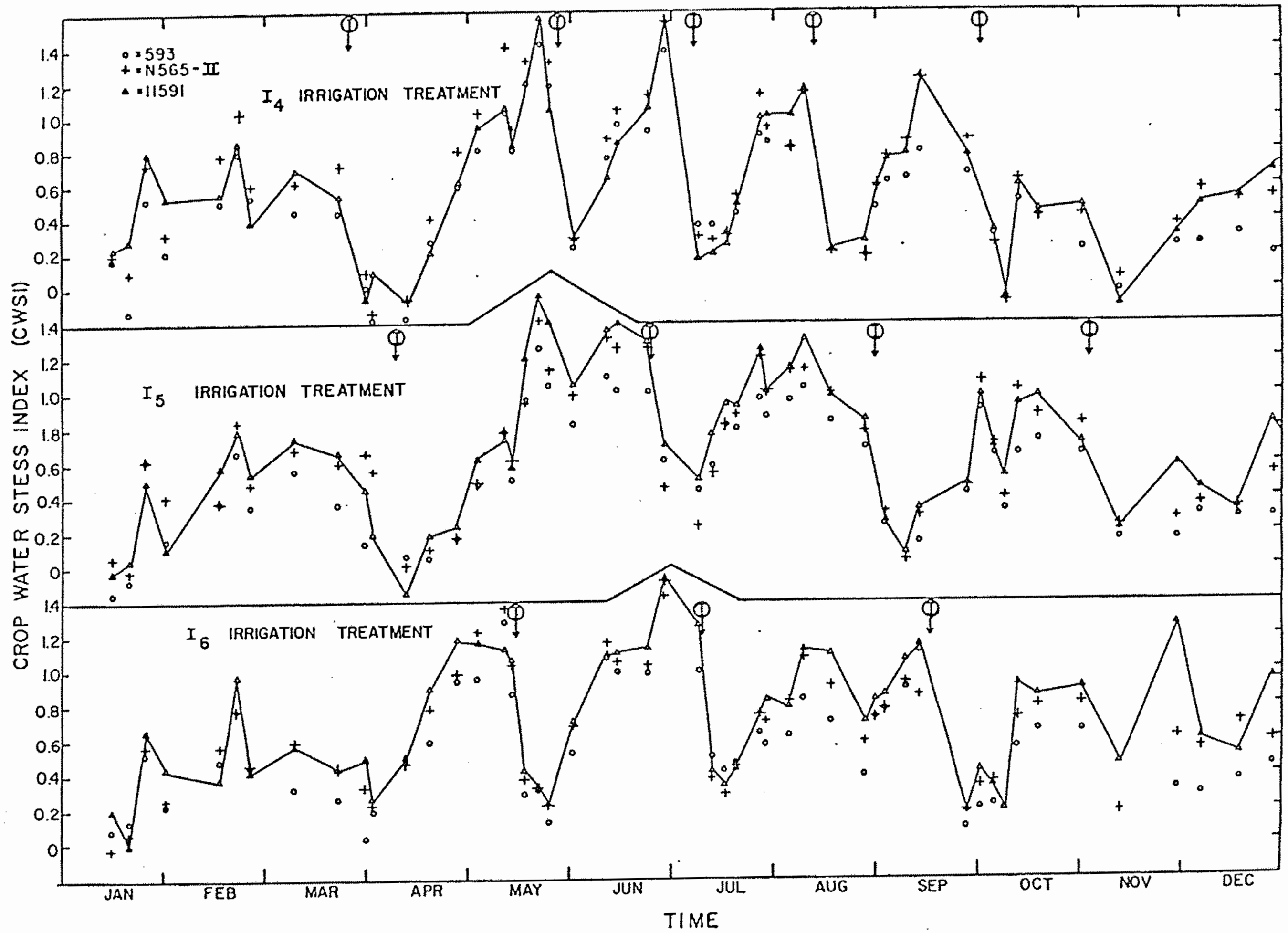


Figure 42. Crop water stress index versus time for three guayule cultivars under the I_4, I_5, and I_6 irrigation treatments at Mesa, Arizona, 1982.

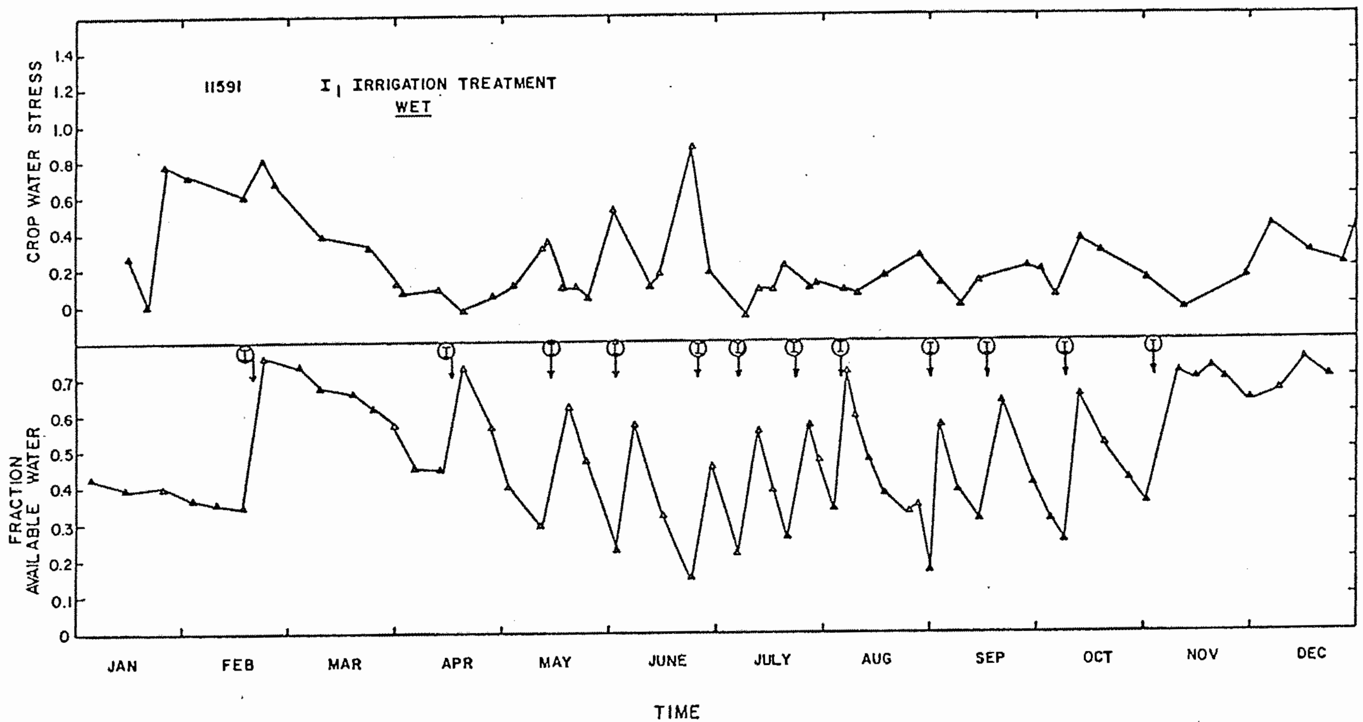


Figure 43. Relationship between crop water stress index and fraction available soil water for cv. 11591 under the I_1 irrigation treatment at Mesa, Arizona, 1982.

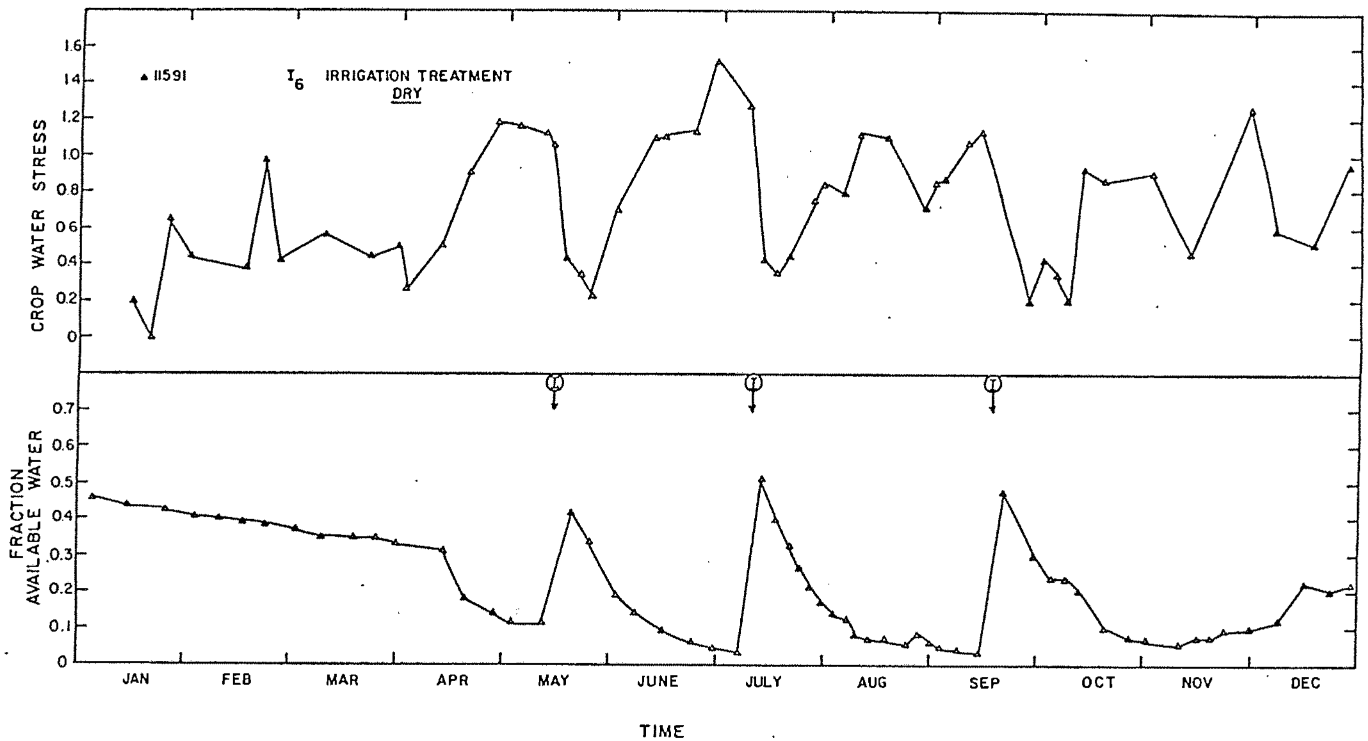


Figure 44. Relationship between crop water stress index and fraction available soil water for cv. 11591 under the I_6 irrigation treatment at Mesa, Arizona, 1982.

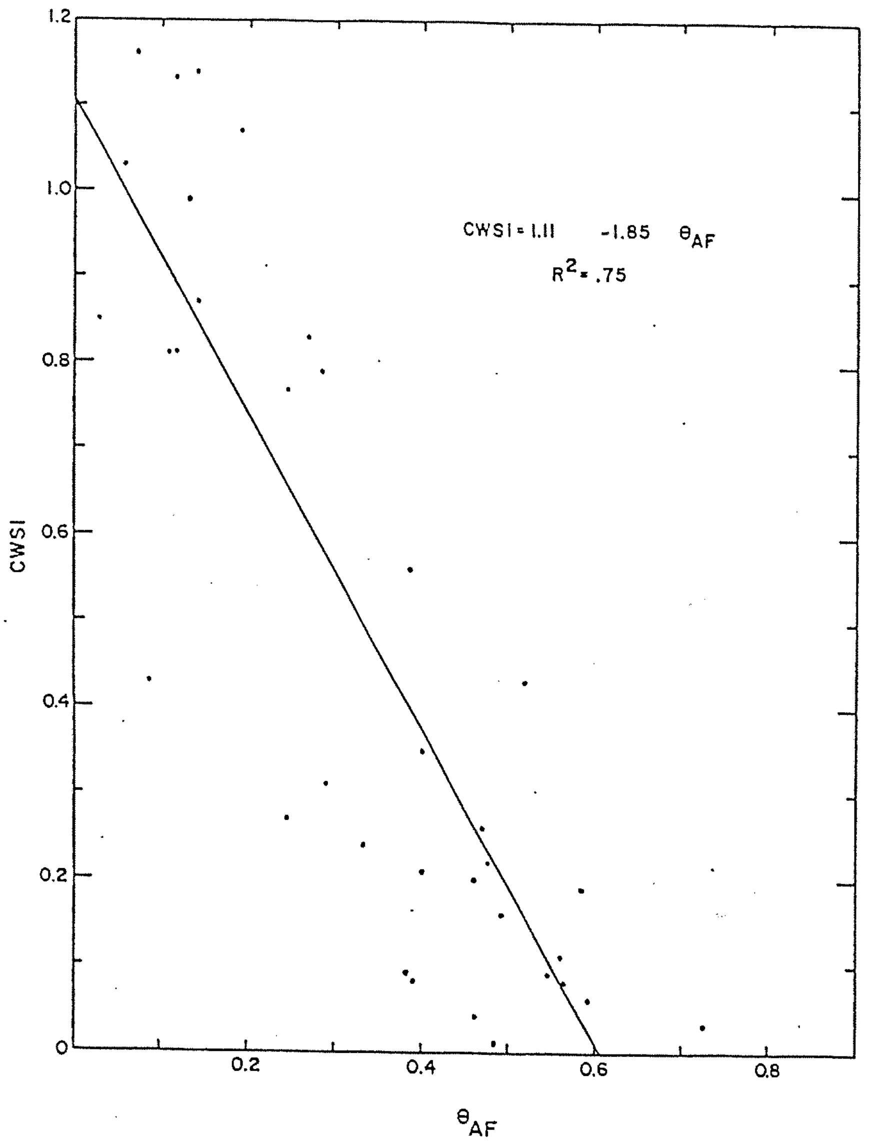
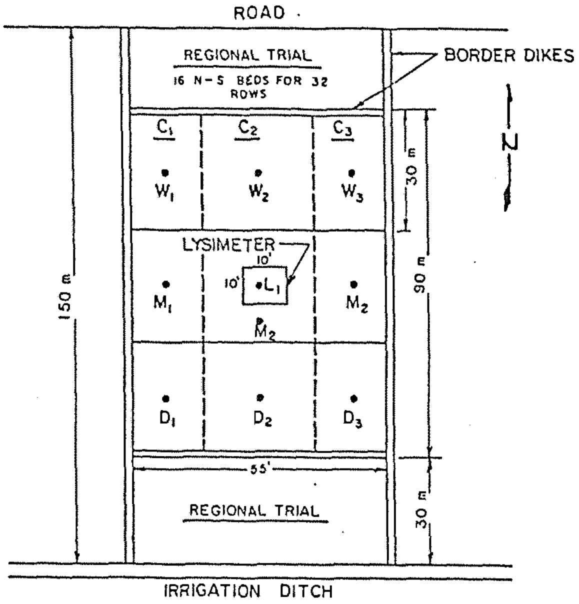


Figure 45. Equation for crop water stress index versus fraction available water for cv. 11591 under all six irrigation treatments at Mesa, Arizona, 1982.

BRAWLEY GUAYULE EXPERIMENT
FALL 1981



IRRIGATION TREATMENTS:

I_1(WET) = 30 % SOIL WATER DEPLETION WITHIN 0-4'(0-110cm) SOIL DEPTH
I_2(MED) = 40 % SOIL WATER DEPLETION WITHIN 0-4'(0-110cm) SOIL DEPTH
I_3(DRY) = 50 % SOIL WATER DEPLETION WITHIN 0-4'(0-110cm) SOIL DEPTH

ADDITIONAL INFORMATION:

• LOCATION OF 10 NEUTRON ACCESS TUBES AT 6'(180cm) DEPTH - W_1, W_2, etc.
CULTIVARS C_1 = 11591, C_2 = N565-II, C_3 = 593, LYSIMETER (N565-II)
PLANT SPACING = 51 x 36 cm 54,000 PLANTS PER HECTARE
PLANTS REQUIRED: 8,000 FOR 0.15 HECTARE
LYSIMETER DEPTH: 5'(150 cm)

Figure 46. Plot diagram, irrigation treatments, and cultivars planted on October 27, 1981, at Brawley, California.

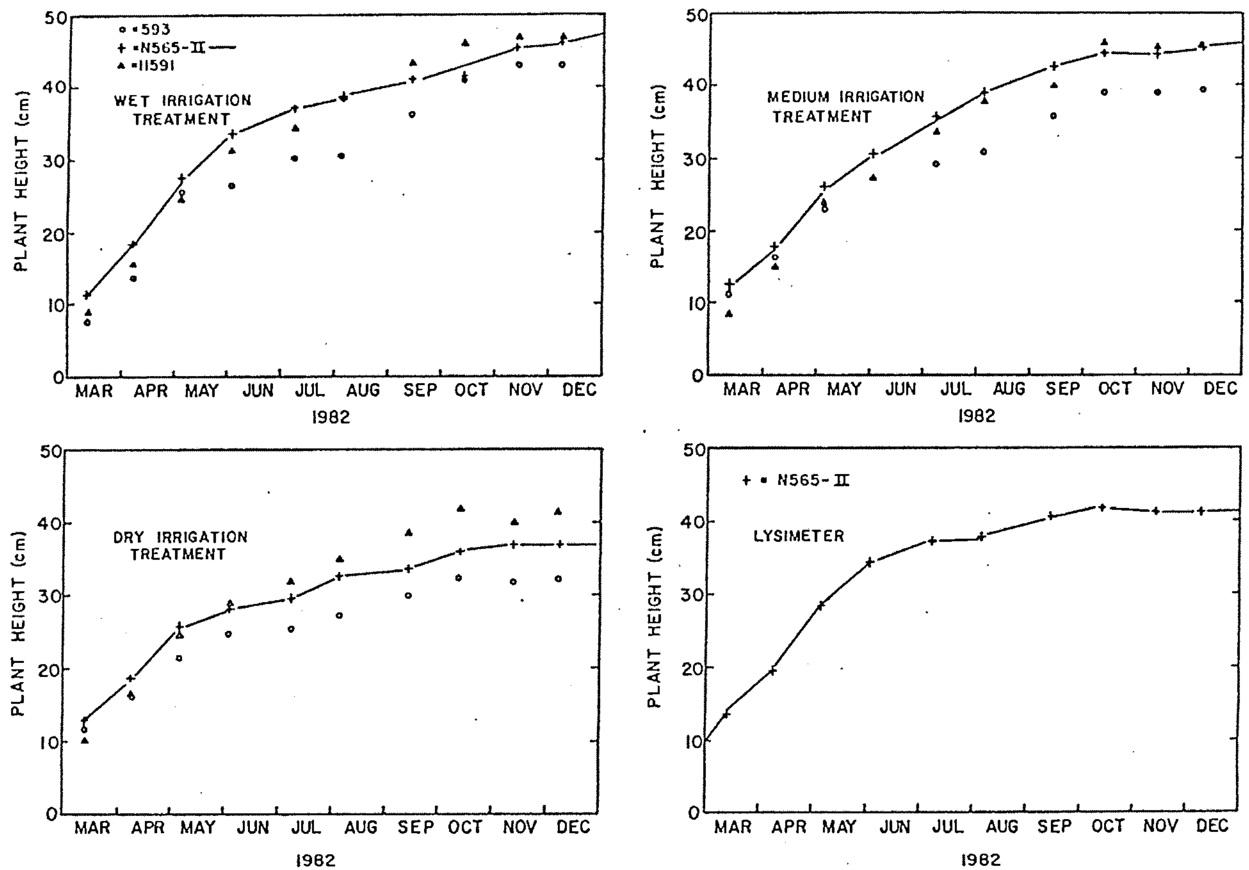


Figure 47. Average plant heights for three guayule cultivars and three irrigation treatments plus lysimeter (cv. N565-II) at Brawley, California, 1982.

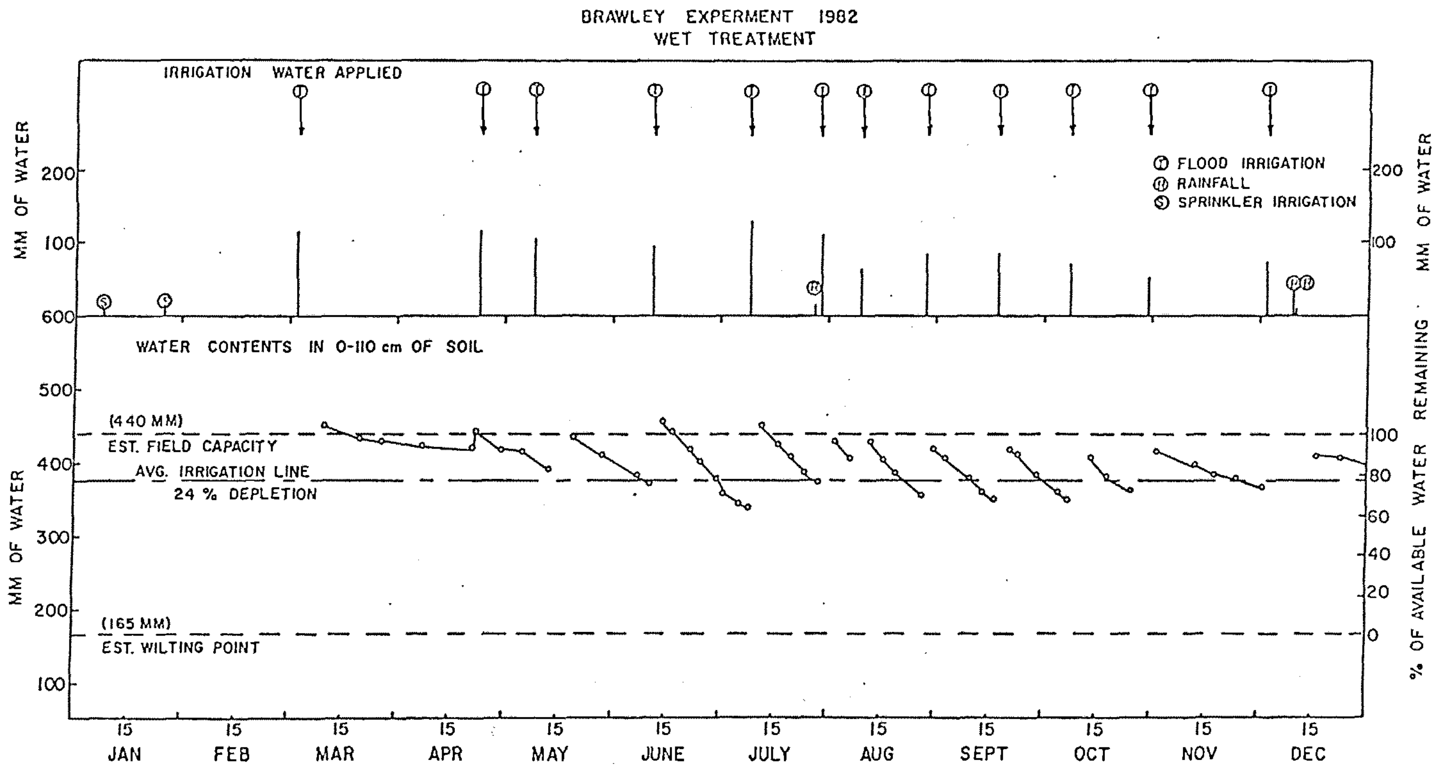


Figure 48. Irrigation water applied and average soil water contents for the wet irrigation treatment at Brawley, California, 1982. (Twelve irrigations were given after 24% of the available soil water was depleted in the 0-110-cm depth).

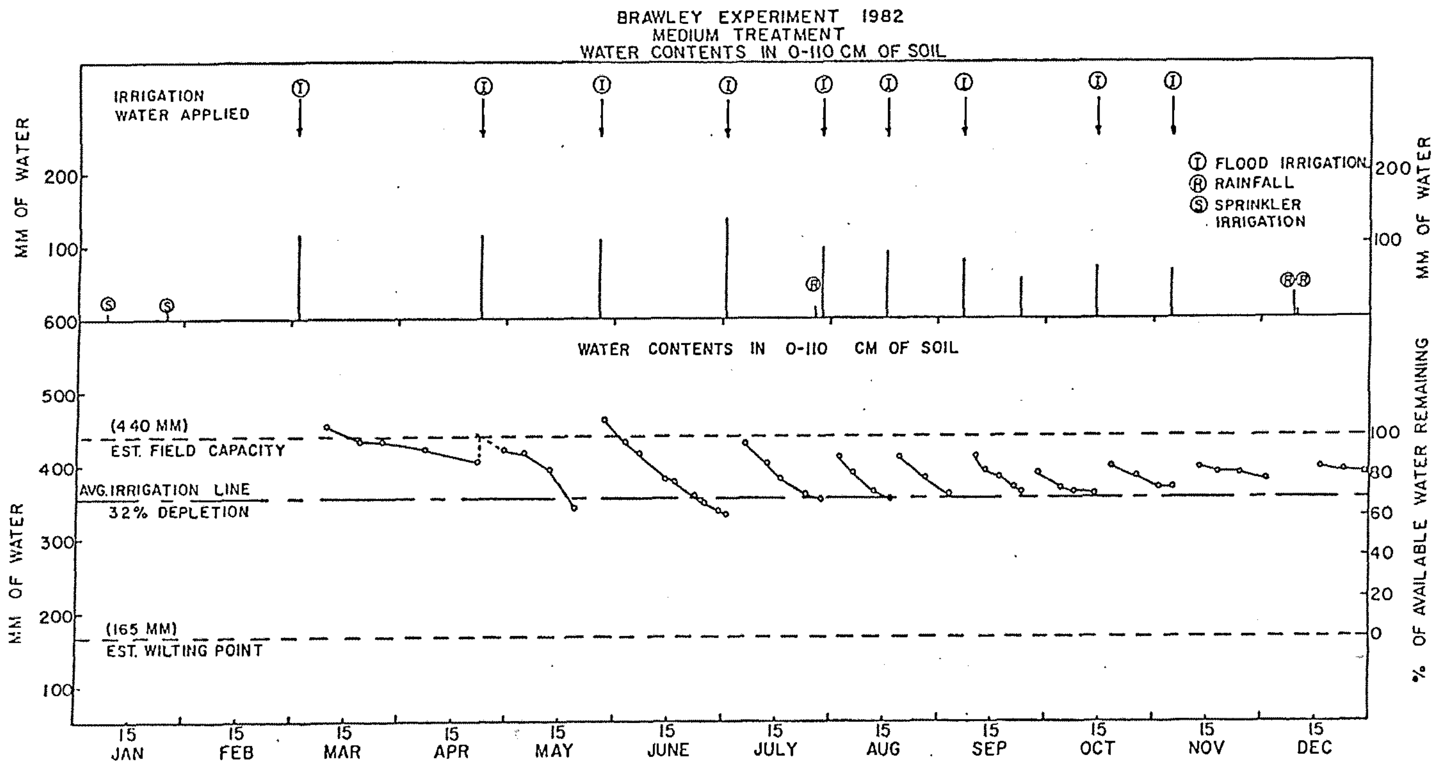


Figure 49. Irrigation water applied and average soil water contents for the medium irrigation treatment at Brawley, California, 1982. (Ten irrigations were given after 32% of the available soil water was depleted in the 0-110-cm depth).

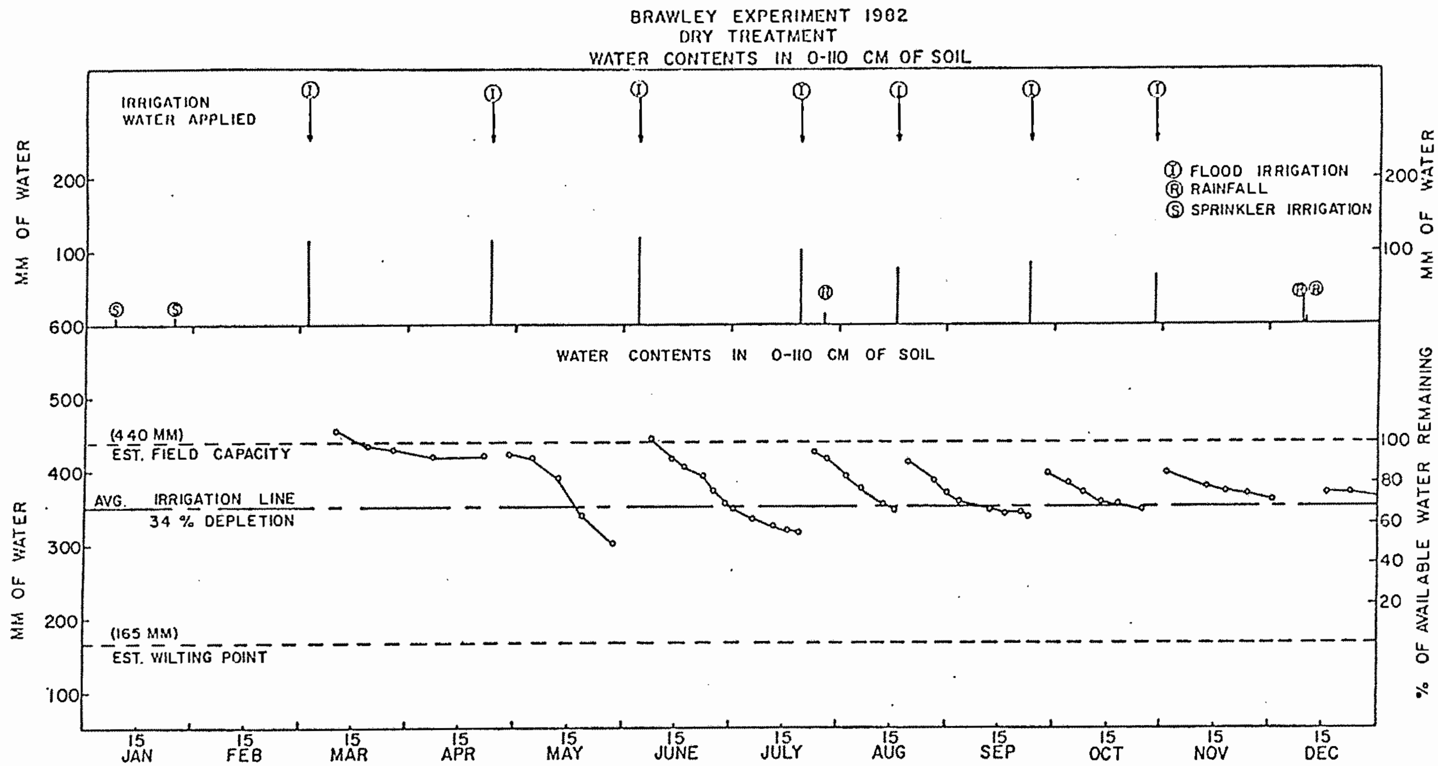


Figure 50. Irrigation water applied and average soil water contents for the dry irrigation treatment at Brawley, California, 1982. (Seven irrigations were given after 34% of the available soil water was depleted in the 0-110-cm depth).

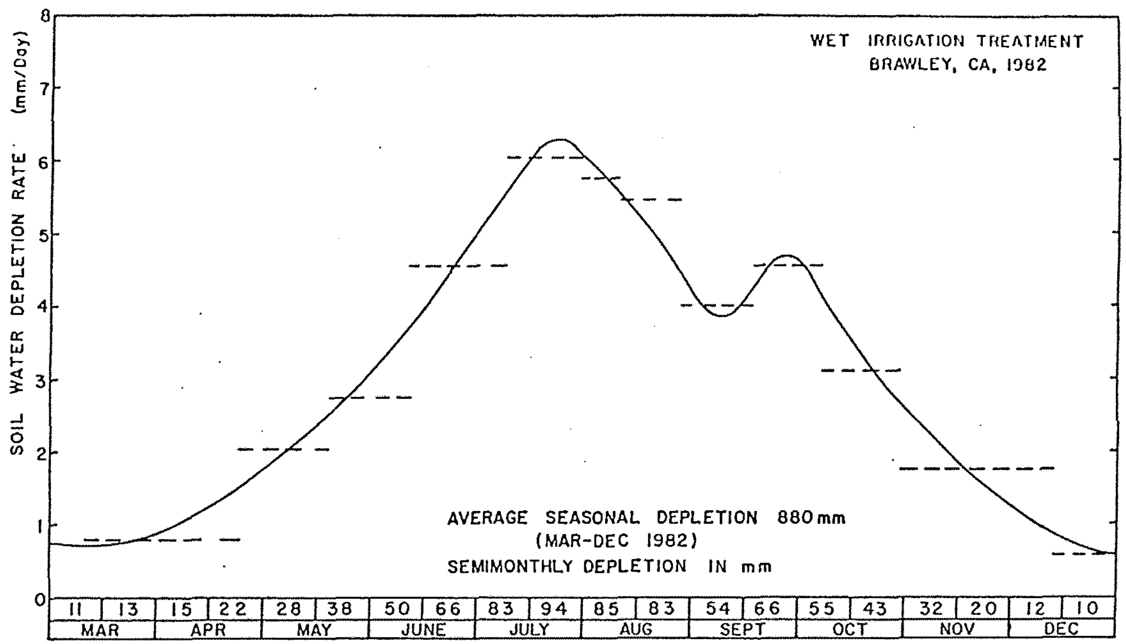


Figure 51. Measured soil water depletion for the wet irrigation treatment at Brawley, California, 1982. (Twelve irrigations were applied after 24% of the available soil water was depleted in the 0-110-cm depth).

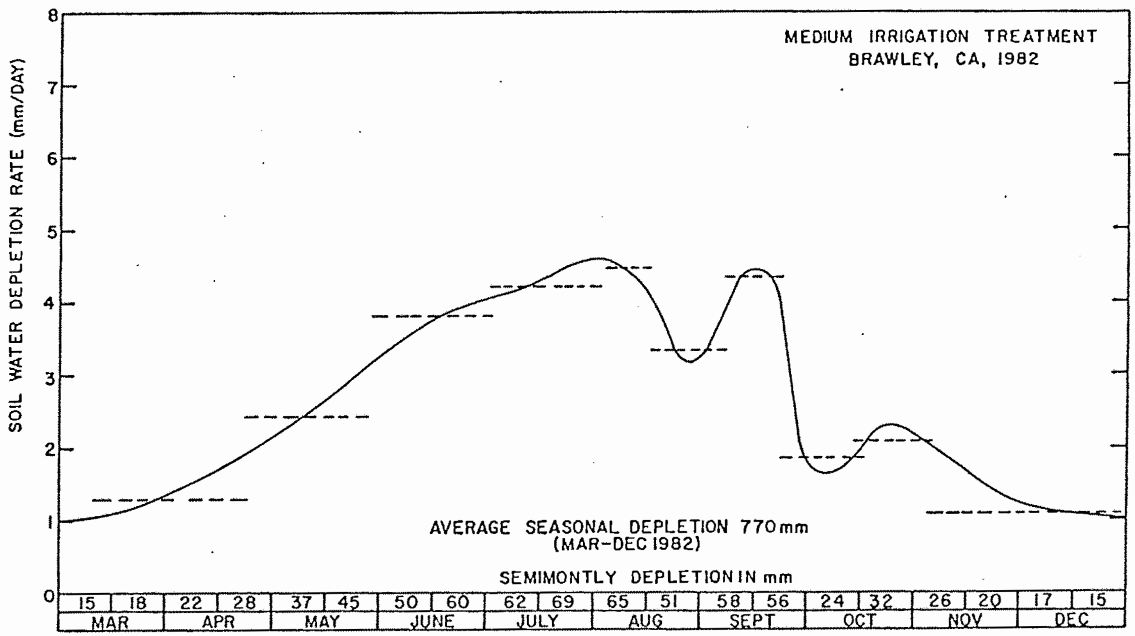


Figure 52. Measured soil water depletion for the medium irrigation treatment at Brawley, California, 1982. (Ten irrigations were applied after 32% of the available soil water was depleted in the 0-110-cm depth).

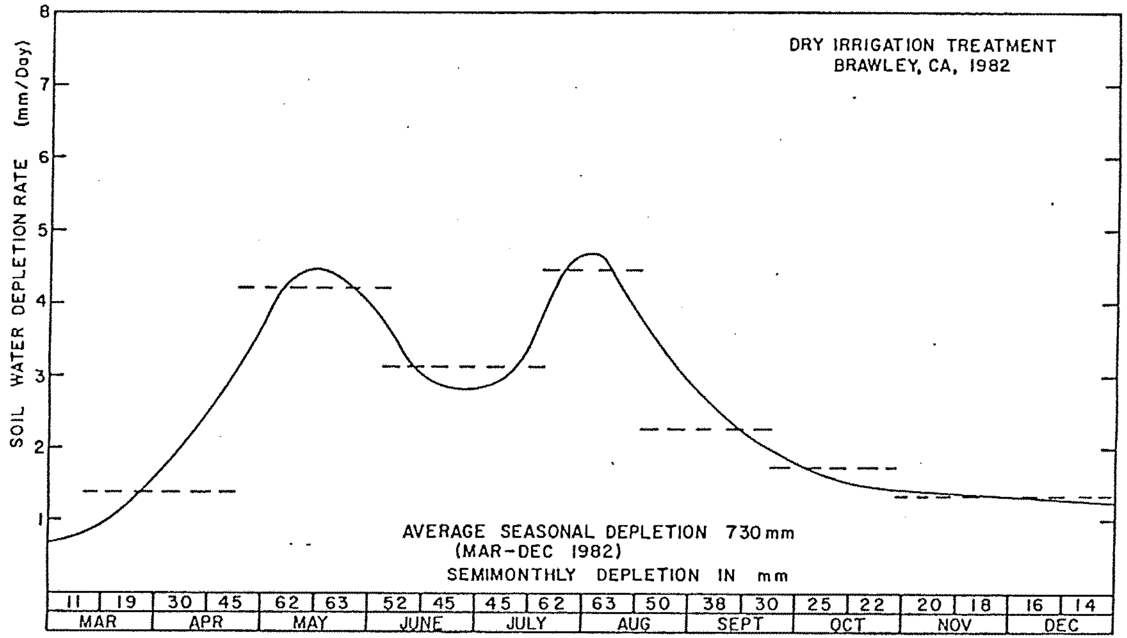


Figure 53. Measured soil water depletion for the dry irrigation treatment at Brawley, California, 1982. (Seven irrigations were applied after 34% of the available soil water was depleted in the 0-110-cm depth).

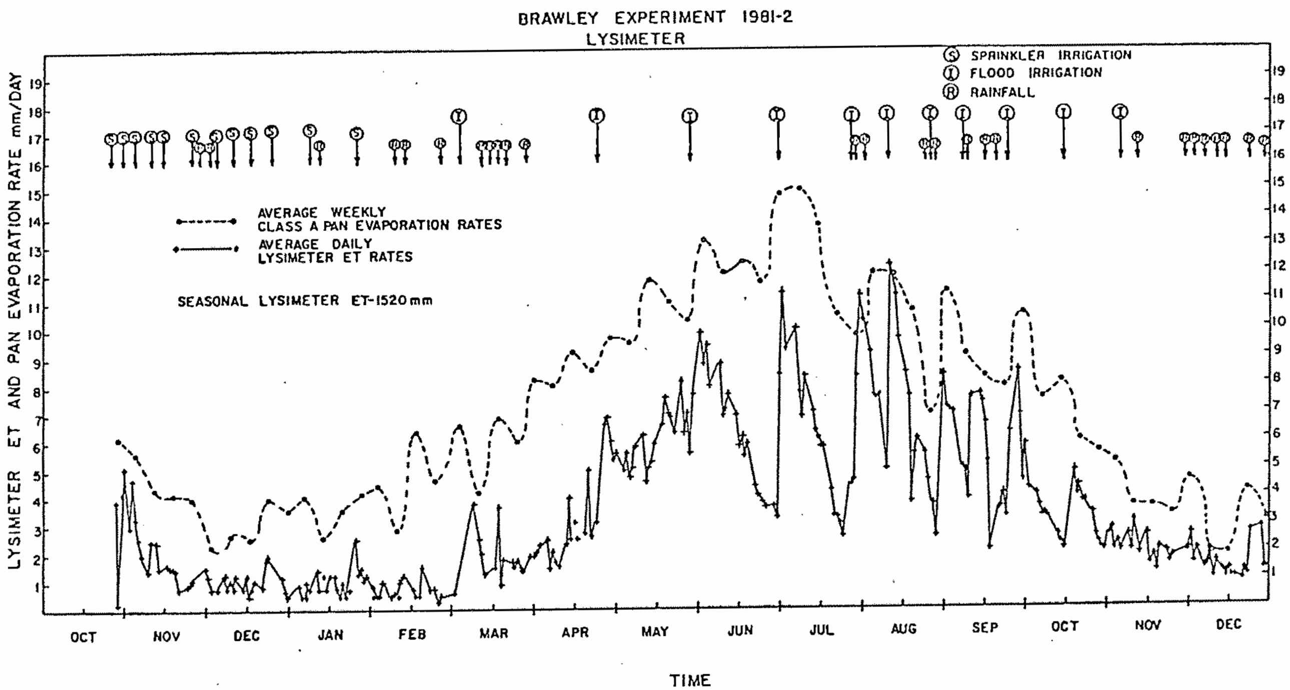
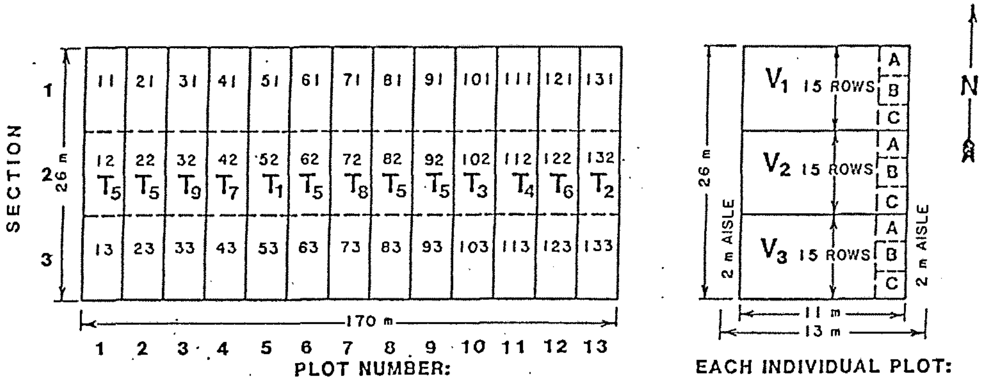


Figure 54. Measured daily lysimeter ET rates and average weekly Class A pan evaporation rates at Brawley, California, 1981-82.

1982 YUMA MESA GUAYULE EXPERIMENT



LEGEND:

WATER APPLIED AND NITROGEN TREATMENTS:

T_1 =50% W.A.,100%N
T_2 =65% W.A.,53%N
T_3 =65% W.A.,147%N
T_4 =100% W.A.,33%N
T_5 =100% W.A.,100%N
T_6 =100% W.A.,167%N
T_7 =135% W.A.,53%N
T_8 =135% W.A.,147%N
T_9 =150% W.A.,100%N
(5 REPLICATIONS)

CULTIVARS:

V_1 =593 V_2 =N565-II V_3 =11591

BIOREGULATORS:

A = 2-DIETHYLAMINOETHYL 1-3, 4-DICHLOROPHENYLETHER
B = 2-DIETHYLAMINOETHYL 1-2, 4-DICHLOROPHENYLETHER
C = N-METHYLBENZYLHEXYLAMINE

PLANT SPACING:
56 x 36 cm

PLANT POPULATION:
49,500 PER HECTARE

PLANTS REQUIRED:
5,850 PER CULTIVAR

Figure 55. Plot diagram, irrigation and nitrogen treatments, cultivars, and bioregulators for guayule plots planted on January 20, 1981, at Yuma, Arizona.

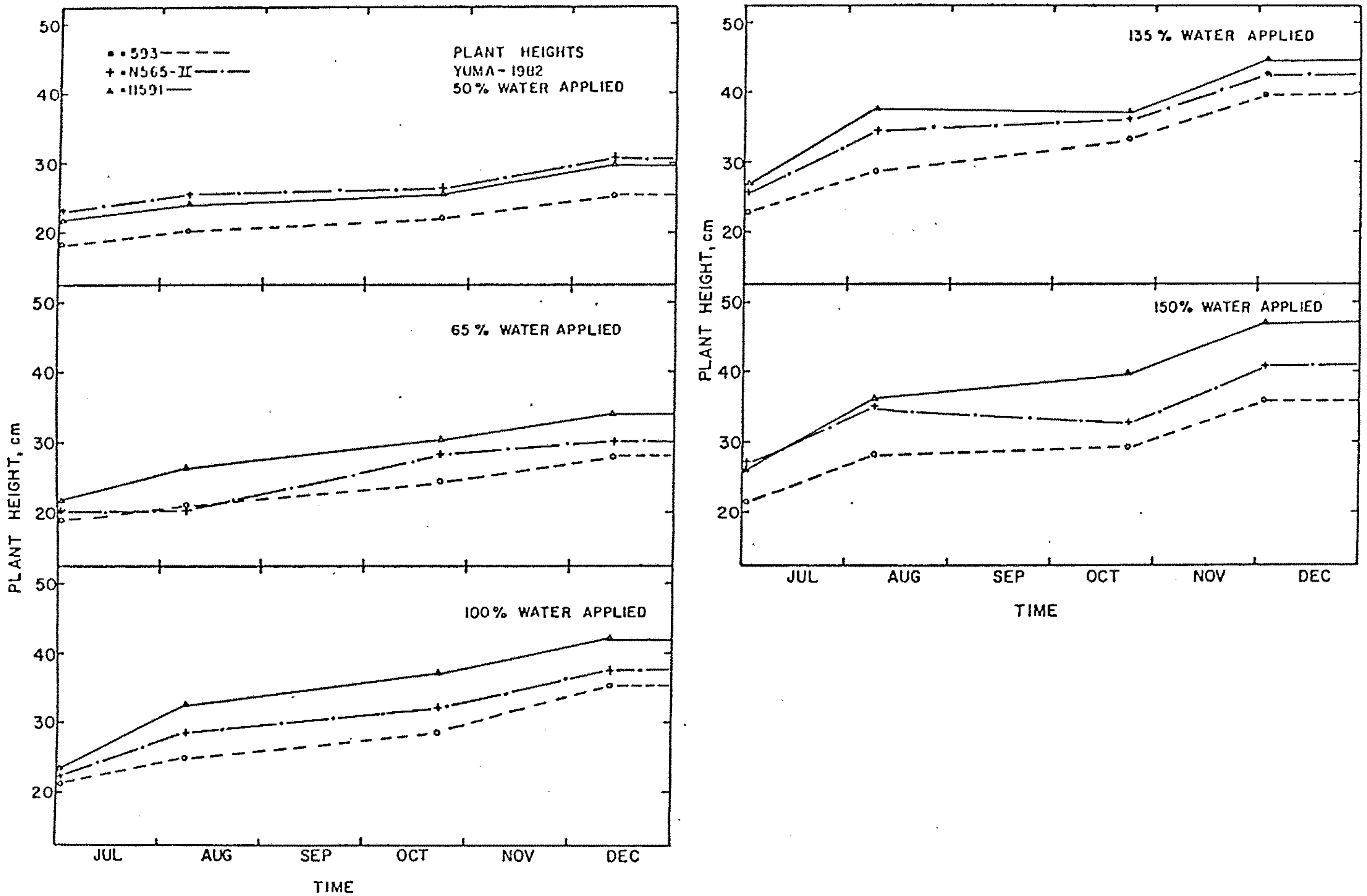


Figure 56. Average plant heights for the three guayule cultivars and five water treatments applied at Yuma, Arizona, 1982.

TITLE: DEVELOPING A CROP WATER STRESS INDEX FOR GUAYULE

NRP: 20740 CRIS WORK UNIT: 5510-20740-012

INTRODUCTION:

The application of the crop water stress index concept to the guayule plant was discussed in the 1981 Annual Report. Experimental results were also presented indicating that the behavior of the guayule plant was similar to other economic crops and that a possibility existed for using this approach as a method for scheduling irrigation.

PROCEDURE:

Plant temperature and related atmospheric measurements necessary to calculate the crop water stress index (CWSI) were continued for the same set of plots. Additional sets of baselines were determined using the method of Idso et al. (1981). Soil water contents were also monitored on a regular schedule.

RESULTS AND DISCUSSION:

Differences between plant and air temperatures for the two varieties of guayule at three irrigation levels are presented in Figure 1. As was noted previously, the 593 variety had slightly higher leaf temperatures than the 11591 cultivar.

The computed CWSI's relative to the available soil moisture for the three irrigation treatments are presented in Figures 2, 3, and 4. Values of CWSI greater than 1, a theoretically impossible situation, were more consistently observed in the 1982 than the 1981 study. In the earlier preliminary study, such observations were assumed to be due to experimental error, but when CWSI's of 2 and higher became consistently evident, some reservations were placed on the computations. First, it was noted that when the vapor pressure deficits were low, (about 1.0 kPa), the indices tended to be greater than 1. Secondly, discrepancies were more prevalent in the dry treatment, where water stress is expected to be the highest. In the 1982 study greater water stress was placed on the plant than in the 1981 experiment, so that more of the larger-than-1 CWSI were being observed. Leaf temperatures of 8 C above ambient were being recorded, whereas the maximum predicted values were on the order of 4 C.

The possible sources of error for observing CWSI discrepancies were further explored. The typical curve from which the CWSI is estimated is reproduced in Figure in 5, where CWSI is calculated from the ratio BC/AC. The baseline curve is derived from measurements of plant temperatures in crops grown in well watered plots. The air temperature and vapor pressures are also determined at the same time to get ΔT and the vapor pressure deficit. The upper temperature limit is estimated by extrapolation of the baseline. AC is computed from that limit to the baseline at the specified VPD. The length BC is the temperature differential of the plant and air temperatures also at the same VPD. The AC values at the different VPD's obtained from experimental measurements and the curved developed for the 593 guayule variety of $\Delta T = 1.76 - 0.15$ VPD and are plotted in Figure 6. The computed upper level maximum temperature difference curve is also plotted. This relation is strickly air temperature dependent, but since the VPD and air temperature is interrelated, a good relationship can be seen.

We can readily see how the same error in air or plant temperature measurements at low VPD and high VPD gives different significance in the overall error. Spring and summer time VPD's are in the 2 to 6 kPa ranges, whereas the late fall and winter values are in the 0.7 to 2.0 kPa ranges. The effects of variation in plant temperature at the "low" and "high" VPD's are compared in Table 1. At 0.8 kPa, one degree variation give CWSI's that are different by 70%. The VPD values in the December to March periods are in this range and the variation in CWSI from one are noticeable in the preceding Figures 2, 3, and 4. The plants are also in a dormant to semi-dormant stage at this time of the year and other measurements indicate that very little water is being utilized by the crop. The baseline, by necessity, was developed when the plant was in the actively transpiring and photosynthesizing state so that it may not be suitable to describe the plant stress status during the dormancy period.

Using the CWSI=1 at various VPD's and one degree temperature difference from that giving a CWSI of 1, new CWSI's were calculated and these are plotted in Figure 7 to illustrate how the errors at the different VPD values compare. As partly indicated in Table 2 the errors will depend upon the vapor pressure deficits at the time of measurements.

Arbitrary errors were introduced in the wet bulb temperatures, which are used to get the vapor pressures, while the other temperatures were kept constant. In this case the computed CWSI remained fairly constant unlike the variation in CWSI caused by errors in the air or plant temperatures. The reason for this is that the VPD is displaced horizontally from point B, (Fig. 5) and the values of AC and BC are adjusted in a similar manner and not to a large extent so that the ratio AB/BC is not drastically changed.

SUMMARY AND CONCLUSIONS:

The behavior of the older guayule plants in regard to the crop water stress index (CWSI) followed closely the ones observed for the preceding crops. Low values were obtained in well-watered plots and high ones for the water-stress plots. Discrepancies observed were explained on the basis that the error in calculating CWSI is related to the vapor pressure deficit (VPD) status of the atmosphere at the time of the measurement. At low VPD typical of the winter months much larger errors are possible than at the drier spring and summer periods. Errors in measuring leaf of air temperatures affected the CWSI calculation much more drastically than errors in the wet-bulb temperatures.

REFERENCES:

Idso, S. B., R. D. Jackson, P. J. Pinter, Jr., R. J. Reginato, and J. L. Hatfield. 1981. Normalizing the stress-degree-day parameter for environmental variability. Agric. Meterol. 24:45-55.

PERSONNEL: F. S. Nakayama, D. A. Bucks, J. M. Martinez, W. W. Legard.

Table 1. Effect of variation in plant temperature on estimating CWSI.

VP (kPa)	T(air) (C)	T(wet bulb) (C)	T(plant) (C)	CWSI
0.776	16.8	12.3	18.9	1.00
"	"	"	18.4	.67
"	"	"	19.4	1.34
"	"	"	19.9	1.67
"	"	"	20.4	2.00
"	"	"	20.9	2.33
"	"	"	21.4	2.67
"	"	"	21.9	3.00
4.18	36.6	23.2	39.3	1.00
"	"	"	39.8	1.07
"	"	"	40.3	1.14
"	"	"	41.3	1.28
"	"	"	42.3	1.42
"	"	"	43.3	1.56
"	"	"	44.3	1.70
"	"	"	45.3	1.84
"	"	"	46.3	1.98
"	"	"	47.3	2.11

Table 2. Effects of variation in wet-bulb temperature on CWSI

T(dry bulb) (C)	T(wet bulb) (C)	VP (kPa)	T(plant) (C)	CWSI
16.8	11.3	0.932	18.9	1.00
"	11.8	.855	"	1.00
"	12.3	.776	"	1.00
"	12.8	.696	"	1.00
"	13.3	.614	"	1.00
"	14.3	.447	"	1.00
36.6	21.2	4.64	39.3	1.00
"	22.2	4.12	"	1.00
"	23.2	4.18	"	1.00
"	24.2	3.94	"	1.00
"	25.2	3.69	"	1.00

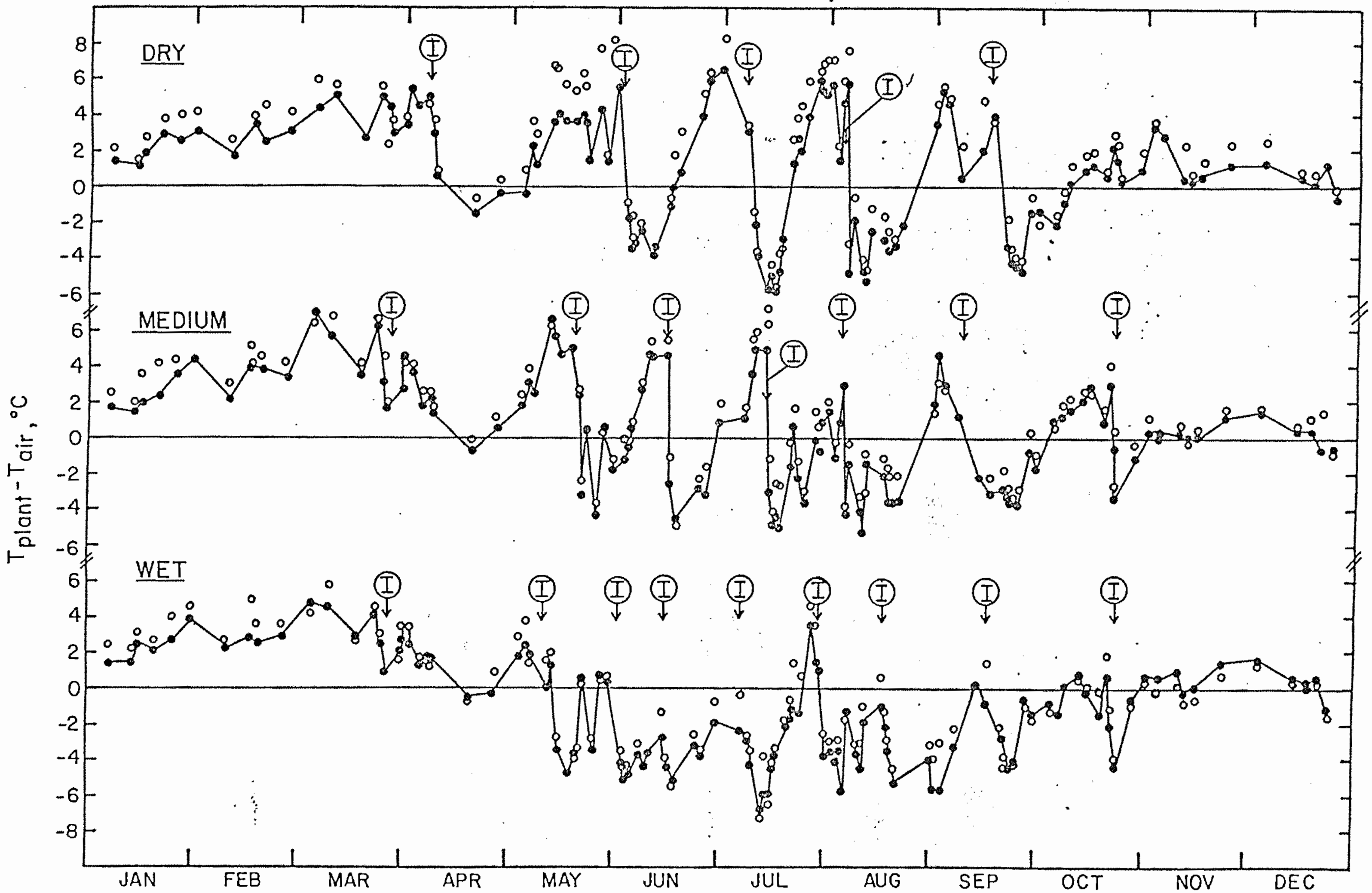


Figure 1. Plant to air temperature differential for two guayule varieties and three irrigation levels. Open circle represents Variety 593 and solid circle 11591.

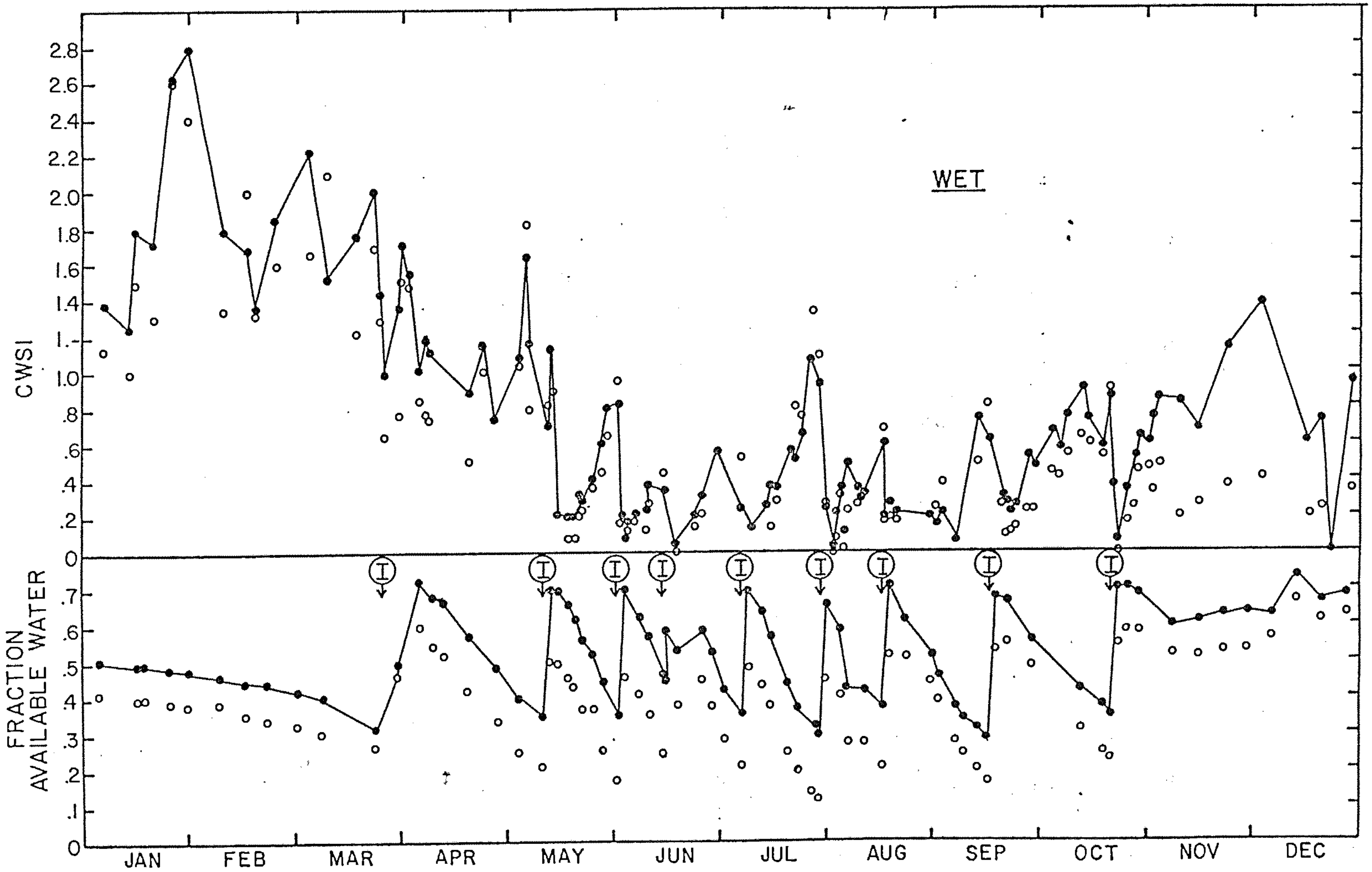


Figure 2. Crop water stress index and fraction water available interrelationship for wet
atm C cir re ent rie 593 so cir 115

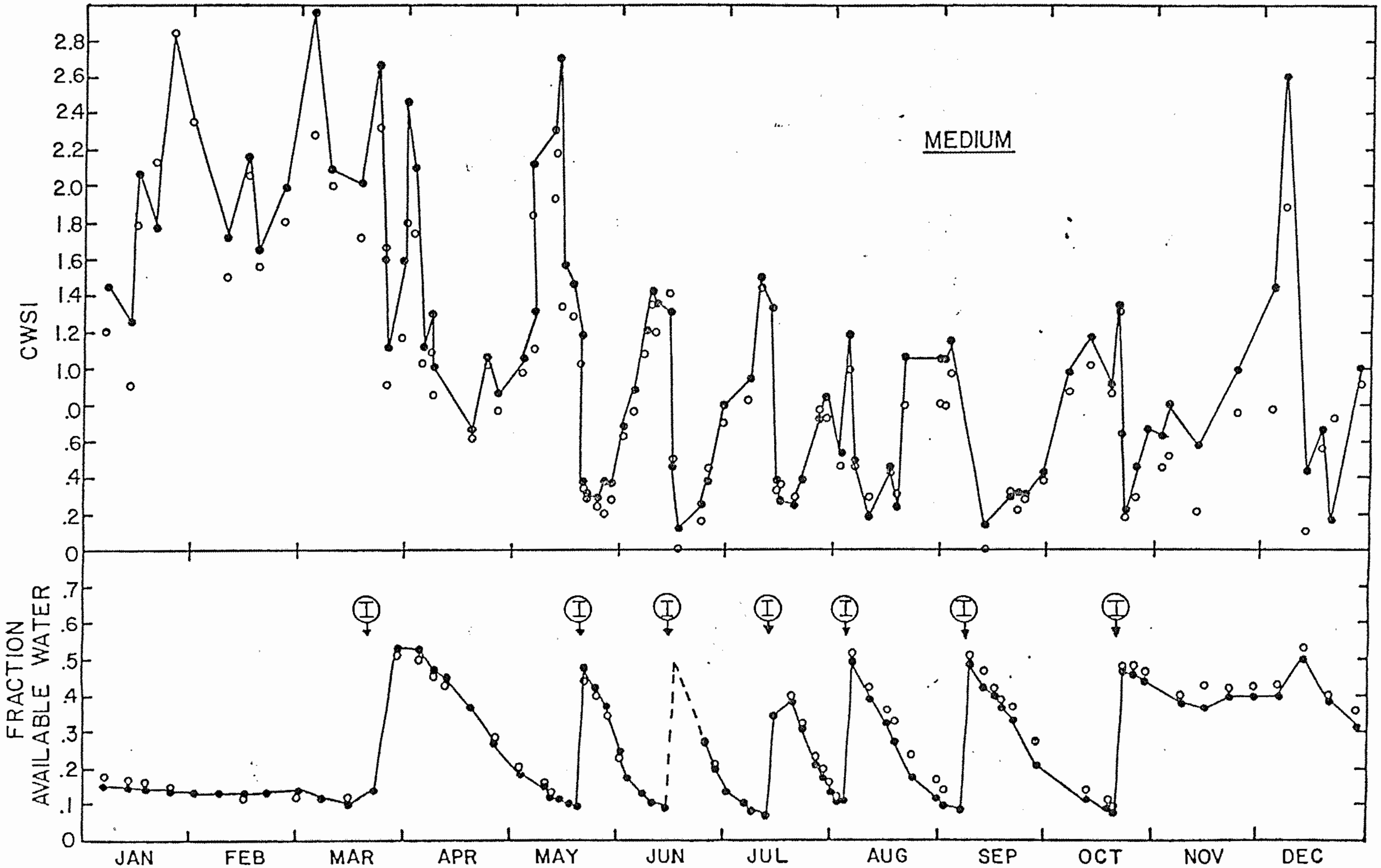


Figure 3. Crop water stress index and fraction water available interrelationship for medium treatment. Open circle represents Variety 593 and solid circle 11591.

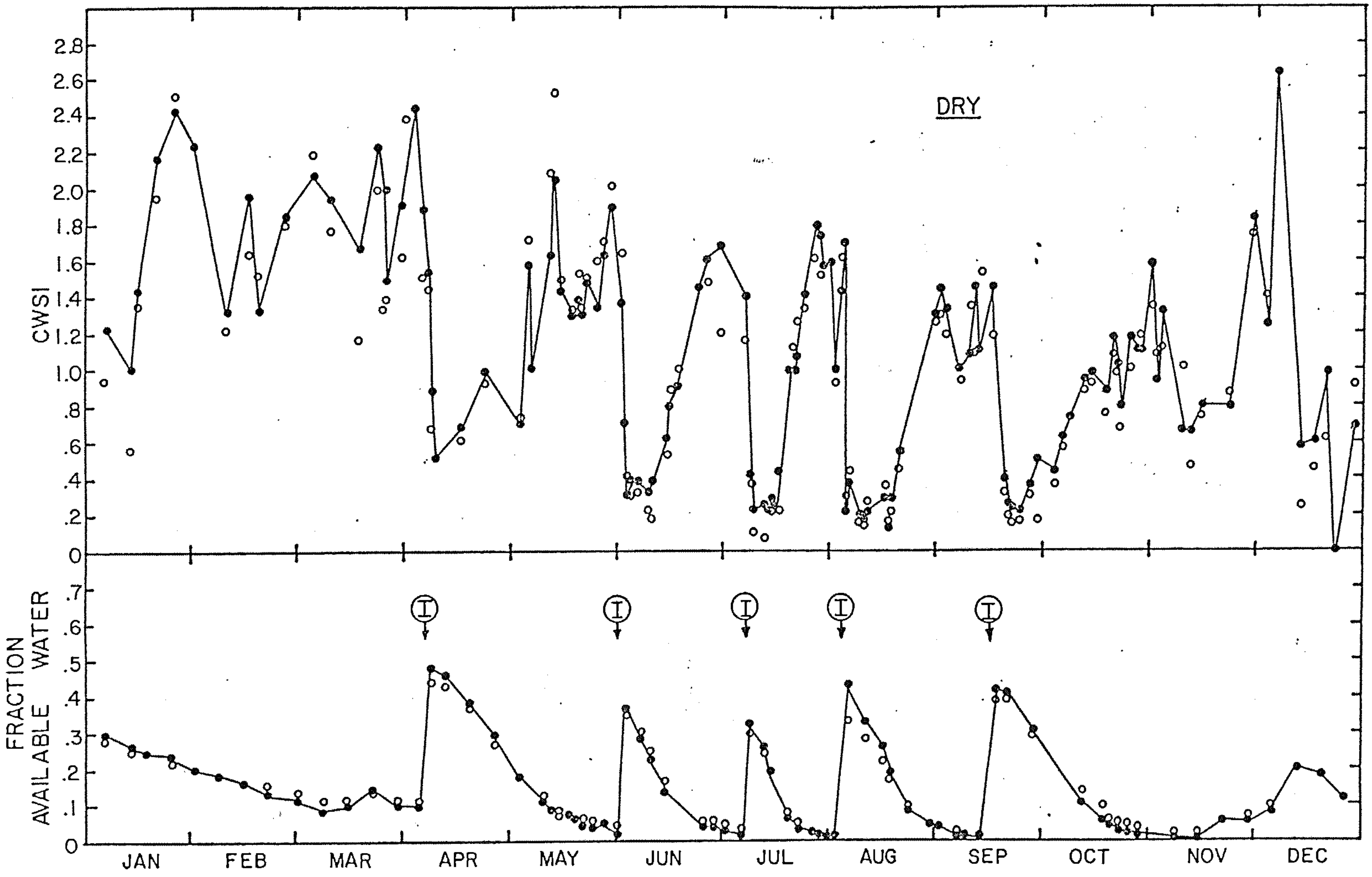


Figure 4. Crop water stress index and fraction water available interrelationship for dry treatment. Open circle represents Variety 593 and solid circle 11591.

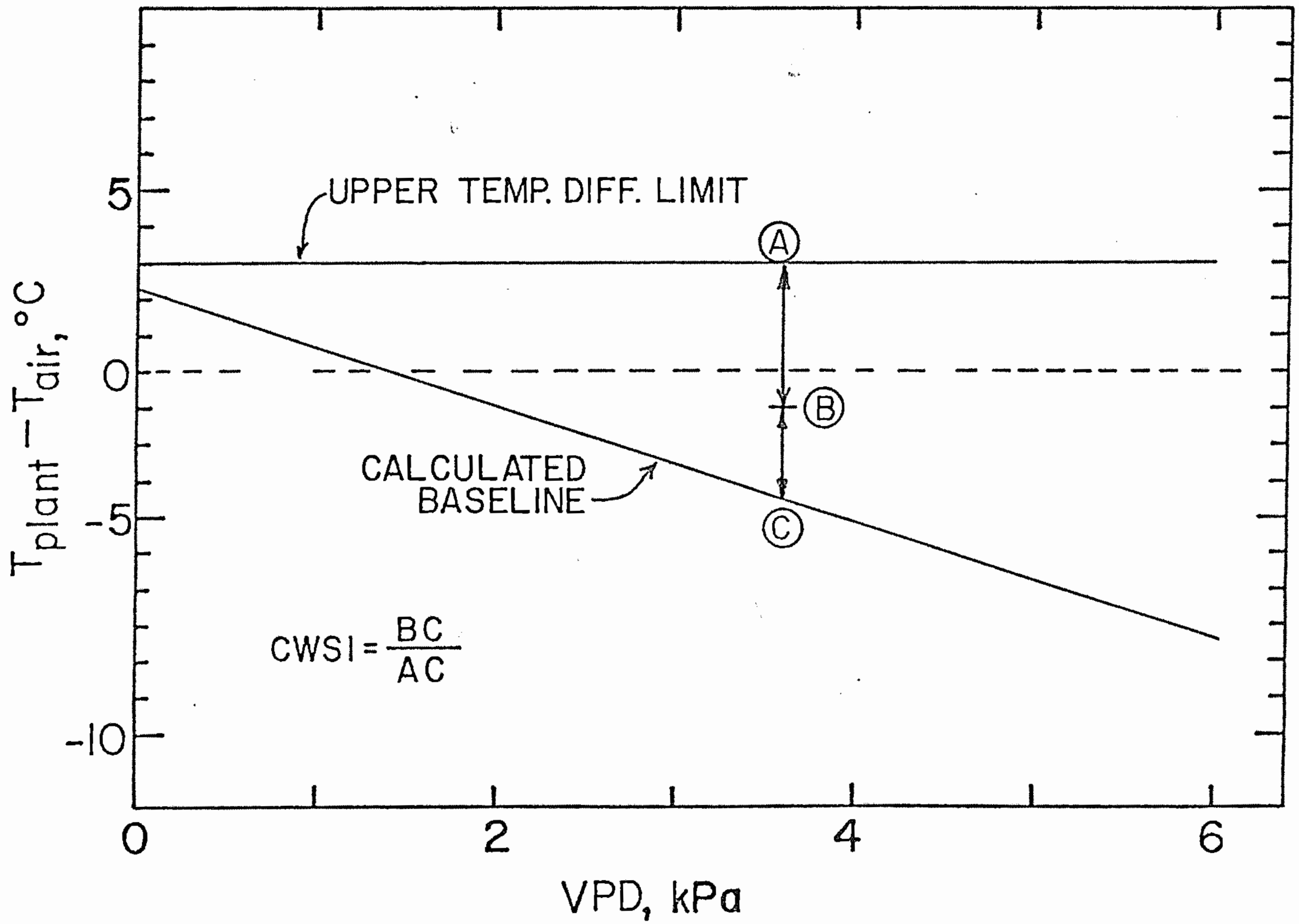
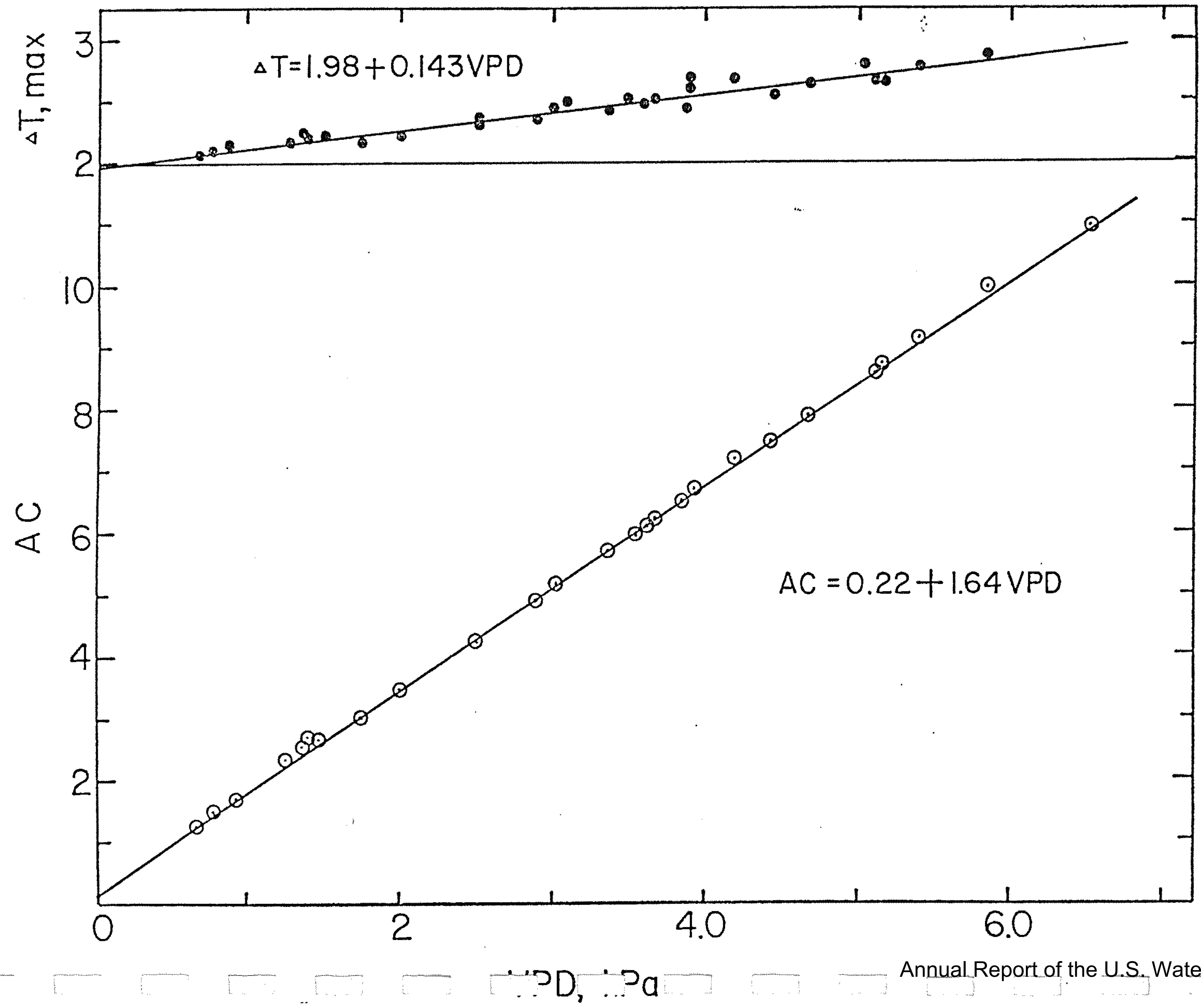


Figure 5. Typical baseline relation developed to compute crop water stress index.


ΔT, max
ΔT=1.98+0.143VPD
AC
AC =0.22+1.64VPD
3
2
10
8
6
4
2
0
2
4.0
6.0
VPD, kPa

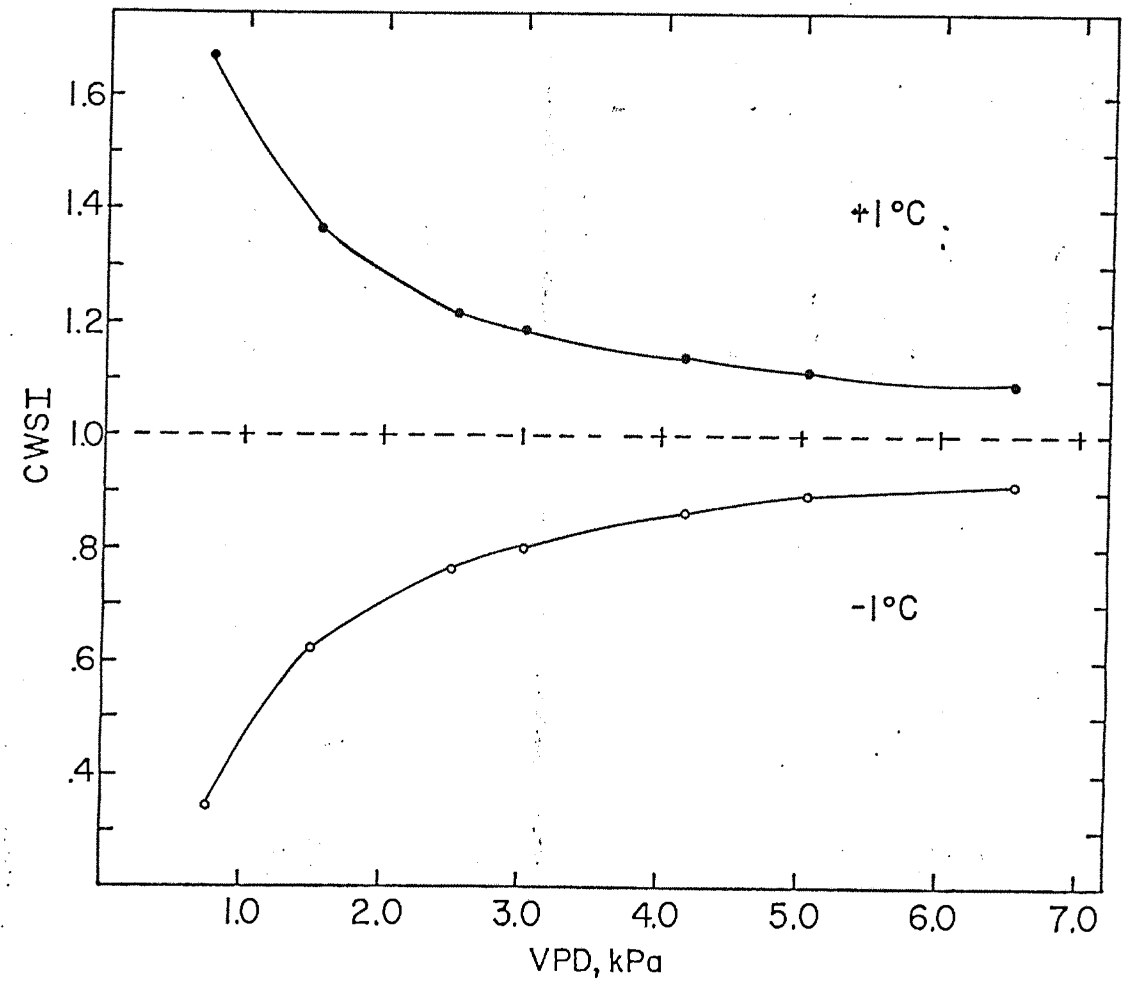


Figure 7. Computed crop water stress index assuming a one-degree variation in plant temperature.

Intensive sampling for following changes in RLWC induced by changes in Θ_v began in mid-June 1981. Data for the wet treatment of cv. 11591 (Fig. 3) show an insensitivity of RLWC to soil water content (Θ_v) at the high levels of Θ_v characteristic of the wet treatment. Irrigation frequency was sufficient to maintain Θ_v above a value of around 250 mm of water per 170 cm of soil. Each of the 10 irrigations shown in Fig. 3 raised Θ_v sharply to values of around 350 mm/170 cm, the rise occurring immediately after irrigation (overnight). The corresponding values of RLWC averaged 80 ± 5%, indicative of leaves under no significant water stress. This is especially noteworthy, since the RLWC data were obtained about an hour after solar noon, when, on a clear day, the evaporative demand generally is quite high and therefore conducive to high rates of evapotranspiration during warm weather.

The data after mid-March 1982 show the same response in shallow (170) and deep (230 cm) soil profiles (Fig. 3).

In the medium treatment (Fig. 4), irrigation was delayed until Θ_v was depleted to 200 mm/170 cm of soil rather than 250 mm. Also, only enough water was applied to restore Θ_v to 300 rather than 350 mm of water. This regime exerted a definite control over the RLWC. Although maxima were high when Θ_v was high, RLWC minima averaged about 50%, and occurred synchronously with the minima in Θ_v.

The sensitivity of the RLWC technique is displayed by the presence of an extra peak in the value of RLWC, occurring not in response to irrigation but rather to the 29-mm rain on 30 July 1981. This rain augmented the water in the soil profile only enough to add a barely perceptible bulge in the declining curve of Θ_v, and yet the RLWC increased notably to a well-hydrated value (80%). It is possible that at least some of this rapid leaf hydration occurred directly through the leaves rather than the root system. The development of a high RLWC was short-lived, however, in hot, sunny weather. The RLWC decreased from about 80% to trough of 50%, before rising again in response to the heavy irrigation of 10 August 1981.

The mid-November through mid-March, soil water contents started to approach the low mid-summer values, but the RLWC decreased to only approximately 70%. This contrasts with RLWC values of 50% for summer at equivalent readings of Θ_v, and probably reflects the much lower evaporative demand in winter than in summer, and also the dormant state of the plant during cold weather.

The dry treatment was extremely harsh, allowing Θ_v to decrease to about 150 mm/170 cm of soil (Fig. 5). However, heavy irrigations restored soil moisture to approximately the same level as in the medium treatment (300 mm). As before, each irrigation was followed by a rise in RLWC, but not so rapidly as in the medium and wet treatments. The range in RLWC was from about 40% to almost 90%, the peak values thus being even higher than those of the two wetter treatments. This may be due to a greater accumulation of solutes in the greatly dehydrated leaves of plants on the dry treatment, leading to a lower leaf water potential and hence a higher inward gradient for water entry.

TITLE: THE EVAPOTRANSPIRATION, YIELD, AND SOIL-PLANT-WATER RELATIONS OF GUAYULE

NRP: 20740 CRIS WORK UNIT: 5510-20740-012

I. Water Stress Status in Guayule as Measured by Relative Leaf Water Content

INTRODUCTION:

Guayule (*Parthenium argentatum* Gray) is a drought-resistant shrub native to Texas and northern Mexico. It synthesizes and stores a high quality rubber equivalent to that from the rubber tree, *Hevea*, the present source of natural rubber for the world. Increasing commercial and military consumption of natural rubber makes the cultivation of guayule an economic possibility, especially because adequate stocks of guayule could make the United States less dependent upon external sources, which in the future could become unreliable.

Earlier research in the United States, carried out on an emergency basis during World War II, provided incomplete information about water requirements and yield potential of guayule. From these efforts, however, emerged the belief that guayule requires less water than agronomic crops commonly grown in the arid Southwest (2). In regard to yield, the best fields had produced about 450 kg of rubber per hectare per year, an amount which probably needs to be doubled to make commercial production feasible. It also was found that stressing the crop for water would increase the percentage rubber and thus help to make up for the lower biomass in a dry treatment (1). If one accepts the premise that percentage rubber is a function of the degree of water stress, than a quantitative measure of this stress might be a guide to irrigation scheduling and prediction of rubber yields. The "relative leaf water content" (RLWC), defined as the ratio of the amount of water in a leaf at sampling to that a full turgor, has been used to determine the moisture status of the plant (7). When a plant transpires more water than it absorbs, the water content diminishes accordingly. RLWC is a measure of the level of leaf hydration, which in turn is associated with photosynthetic rate, growth, and ultimately, yield.

This report documents the effect of large differences in soil water content (wet, medium, and dry irrigation treatments) on the annual course of RLWC in two cultivars of guayule.

PROCEDURE:

Guayule cultivars 593 and 11591, were grown in the greenhouse for three months and then transplanted (April, 1981) to a field at the U. S. Water Conservation Laboratory, Phoenix, AZ, in plots 3 x 1.8 m. Row spacing was 46 cm and plant spacing 36 cm (62000 plants per hectare). There were four rows per plot. An inner row adjacent to an access tube for measuring soil water content (Θ_V) by a neutron probe was used for RLWC measurements. Eight plots constituted a given irrigation level, for a total of 24 plots. Within an irrigation level, the two cultivars were replicated four times and randomized. Within each irrigation level there were two neutron meter access tubes for each cultivar, making a total of 12 moisture sampling sites. The access tubes were installed originally to a depth of 160 cm in 1981 and increased to 230 cm in May 1982. Readings of water content were taken every 20 cm from 20 through 160 cm, and later to 220 cm. The readings were made with Troxler Electronic Laboratories, Inc.[2] or Campbell Pacific Nuclear Corporation[2] equipment three times a week from spring through fall, and weekly during winter. The equipment was calibrated in the same soil as the experimental plots.

The three irrigation levels were: (1) wet, irrigation when 80% of the "available water" in the soil between 10 and 170 cm was depleted; (2) medium, with 90% depletion, and (3) dry, with 95% depletion. The term available water was defined as the quantity of soil water between the wilting point (11% by volume) and field capacity (28% by volume) for the Avondale clay loam. Metered irrigations were applied through double tube trickle lines under control of a time clock. After the plants were established in late July, differential irrigations began.

Because the petiole of guayule could not be clearly distinguished from the blade, the whole leaf was used to determine the RLWC. An integrated sample of the entire 10-plant row was obtained by taking one leaf from each of six plants and two leaves from two other plants, avoiding the plant at each end, which served as a border. The total of ten leaves was used as a unit, and was weighed with a precision of 0.0001 gram.

After the leaves were picked, they were immediately placed in tightly stoppered vials and put in an insulated box. After the six plots were sampled (two cultivars x three irrigation levels) the process was repeated for a duplicate set of values. The vials then were taken to the laboratory and weighed. The duplicate sets of readings were averaged. They seldom differed by more than 10 percent, and often less than 2 percent. Samples were taken at least weekly over most of the warm season and additionally when warranted by the need to document plant water status just before or shortly after an irrigation.

Hydration period.

To validate the RLWC technique, time course curves were run by sampling leaves from the field plot and hydrating them for varying periods. Leaves of cv. 11591 differing greatly in their initial hydration level (the first set being picked three days, and the second three weeks after irrigation) were tested. The 10-leaf samples were placed in a hydrator of clear glass, with the petioles immersed in about 2 cm of water in vials which were set on a perforated plate just above the water level.

[2] Trade names and company names are included for the benefit of the reader and imply no indorsement or preferential treatment by the U. S. Department of Agriculture of the product listed.

A tight lid and the evaporation of water soon brought about saturation vapor pressure of the air above the leaves. The temperature was maintained at 27 ± 2 C, and illuminance at 600 lux. After the hydration period, the leaves were placed on paper towels for a few minutes and then lightly blotted dry, followed by weighing. Then they were oven dried at 55 C and reweighed. The calculations were as follows:

$$RLWC = \frac{Wf - Wd}{Ws - Wd} (100)$$

where Wf = the weight at sampling,
Ws, that at full hydration, and
Wd, the oven-dry weight.

Time of day for sampling.

In addition to the determination of the proper hydration time, it was necessary to develop a criterion for the most sensitive time of day to sample leaves, since it is well established that many plant parameters undergo a diurnal variation. Accordingly, three diurnal runs were made, utilizing both guayule cultivars.

The RLWC data presented here were obtained in conjunction with comprehensive measurements of canopy-air temperature differences in relation to the same large differences in soil water content that are shown here. Both sets of data were obtained for a year, and measurements will continue until harvest of the guayule crop for analyses of rubber content.

RESULTS AND DISCUSSION

Water absorption by the detached leaves as a function of hydration time is shown in Figure 1. As might be expected, the leaves from the dry treatment absorbed water at a much more rapid rate than those from the wet treatment. Full hydration may have occurred at 16 hours or slightly less, but the 24-hour contact was adopted as the standard exposure period.

The results of the most comprehensive of the three diurnal runs are shown in Figure 2. The RLWC did not undergo much change during the day, extending in time from 0600 h to 2000 h, although the pre-dawn readings were somewhat higher than those later in the day when radiation and evaporative demand were higher. It was decided to standardize the sampling time at an hour beyond solar noon. Actually, the results show that the RLWC during the period of 1100 through 1700 hours were similar. The 1300-hour time was convenient, since leaf temperature and other meteorological measurements also were taken at this time. The large differences in soil water content, ranging from 180 to 348 mm of water in the 170-cm soil profile, were reflected in RLWC values from about 45% to 85%, with some overlap of the medium and wet treatment data.

The same phenomenon as before occurred in regard to the response of RLWC to rain in the absence of irrigation, except that this time it was even more striking, in view of the lower rainfall total, 16.3 mm. Although the total amount of soil moisture in the 170-cm profile decreased slightly (1.1 mm from 12 to 14 August), the upper layers (20 through 60 cm) gained 18 mm. This was only 11% of the amount of water that is added to the profile in a normal irrigation. Despite a rather small gain in soil water content, the RLWC rose sharply over this interval, from 62 to 78%.

It appears that (1) either shallow roots are extremely effective in water absorption (presumably not too likely in view of the extreme surface dryness, which would tend to kill root hairs), or (2) the greatly dehydrated leaves at least partially rehydrated by direct absorption through the epidermis.

Although the response of RLWC to large changes in soil water content was similar in the two cultivars, there was a small but consistent difference, being most notable in the dry treatment (Fig. 6). Cultivar 593 dehydrated to the extremely low value of near 30% RLWC, as compared to near 40% for cv. 11591. These values contrast with those of fava bean (3), for example, grown in England where even in a dry summer, with the soil water potential at -150 kPa, the RLWC decreased to only 64%. Such a comparison is difficult to make, however, because as Ladiges (4) pointed out in working with three populations of *Eucalyptus viminalis*, not only edaphic but also climatic factors must be considered as affecting the RLWC.

Despite the very low values of RLWC attained by guayule, both cultivars rapidly recovered to a well-hydrated state. This recovery in RLWC was accompanied by a considerable increase in leaf area, as much as 30%. The regaining of both leaf hydration and area was more rapid than that of sunflower found by Rawson and Turner (5), which could be observed three days after irrigation of a previously dry soil. It is apparent that guayule is remarkably well adapted to survive under extremely arid conditions and able to exploit rapidly drought alleviation.

Statistical analyses were made relating the RLWC to the amount of moisture in the 0 to 170-cm soil profile for the various treatment-variety combinations. Cultivar 593 was chosen to illustrate the trend for the *dry* treatment (Fig. 7) The r value from the least squares best fit statistical treatment was 0.93 for soil water contents between 175 to 210 mm in the 170 cm of soil depth. When the soil water content was 210 mm or more, leaf hydration was high: RLWC = 76% (for the given conditions of midday reading on clear days).

Table 1 summarizes the data for all six combinations. In cv. 593, the RLWC was linearly related to soil water content in all three irrigation treatments (the r values being 0.78, 0.66, and 0.93 for the *wet*, *medium*, and *dry* treatments, respectively). The respective slopes of the linear regression curves were 0.31, 0.34, and 1.29, and all were statistically significant (P = 0.001). However, the range of linearity differed among treatments, being from 175 to 210 mm (dry); 185 to 250 mm (medium); and 220 to 250 mm (wet). Values of soil water content above these maxima brought about maximal RLWC, i.e, around 76%. As an example, for cv. 593 this means that 210 mm of water in the soil profil would be sufficient to induce maximal RLWC in the dry irrigation treatment, whereas 250 mm would be needed for the other two treatments. This may indicate an ability of plants in the dry treatment to "overcompensate" in comparison to the wetter treatments. Such overcompensation occurred in sunflower (5). When plants in a very dry treatment were given a single irrigation, leaf water potential rapidly increased to levels characteristic of the wet treatment. Also, partly expanded leaves whose growth had slowed down significantly due to water stress, renewed their leaf expansion and attained a final leaf area greater than that of leaves in the wet treatment.

For cv. 11591, in the dry irrigation treatment, the linear regression of RLWC on mm of water in the profile was highly significant (P = 0.001), with a slope of 1.15 over the soil water content range of 175 to 200 mm. At water contents greater than about 200 mm, the linear regression still was significant in the medium treatment (P = 0.01), but the slope was only 0.13. The extremely high water levels of the wet treatment, ranging from 250 to 390 mm in 170 cm of soil, caused the RLWC to be independent of the soil water contents measured.

SUMMARY AND CONCLUSIONS:

The data from the year-long set of measurements demonstrate a varietal difference in the response of leaf hydration, or relative leaf water content of the guayule plant to soil water content. Cv. 593 consistently extracted soil water to a slightly lower value than cv. 1159 On the other hand, application of the regression constants for the two cultivars shows that, for a given soil water content, cv. 593 maintains a slightly lower RLWC than cv. 11591. Although the preponderance of current research on guayule deals with irrigated conditions, the plants's extreme drought tolerance and rapid resumption of growth after a rain or irrigation make it an ideal candidate for dryland agriculture, provided that economic returns are favorable.

The RLWC technique applied to guayule an hour after solar noon and repeated throughout an irrigation cycle can be a sensitive indicator o soil water depletion. Therefore, this method or an abbreviated form o it, where sampling would be done just before and after a rain, may be a useful guide to irrigation scheduling.

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PERSONNEL: W. L. Ehrler, D. A. Bucks, and F. S. Nakayama

Table 1. Parameters for the linear regression of relative leaf water content on the amount of water in the soil (mm in 0 to 170 cm depth) for guayule cvs. 593 and 11591.

	GUAYULE							
	cv. 593				cv. 11591			
Treat.	Data Pairs	Corr. Coeff.	Slope	Stat. Sig.[a]	Data Pairs	Corr. Coeff.	Slope	Stat. Sig.[a]
Wet	30	0.78	0.31	***	25	0.39	0.13	N.S.
Med.	40	0.66	0.34	***	43	0.49	0.13	**
Dry	26	0.93	1.29	***	28	0.92	1.15	**

[a] Statistical significance: ** P=0.01; *** P=0.001; N.S. = not significant

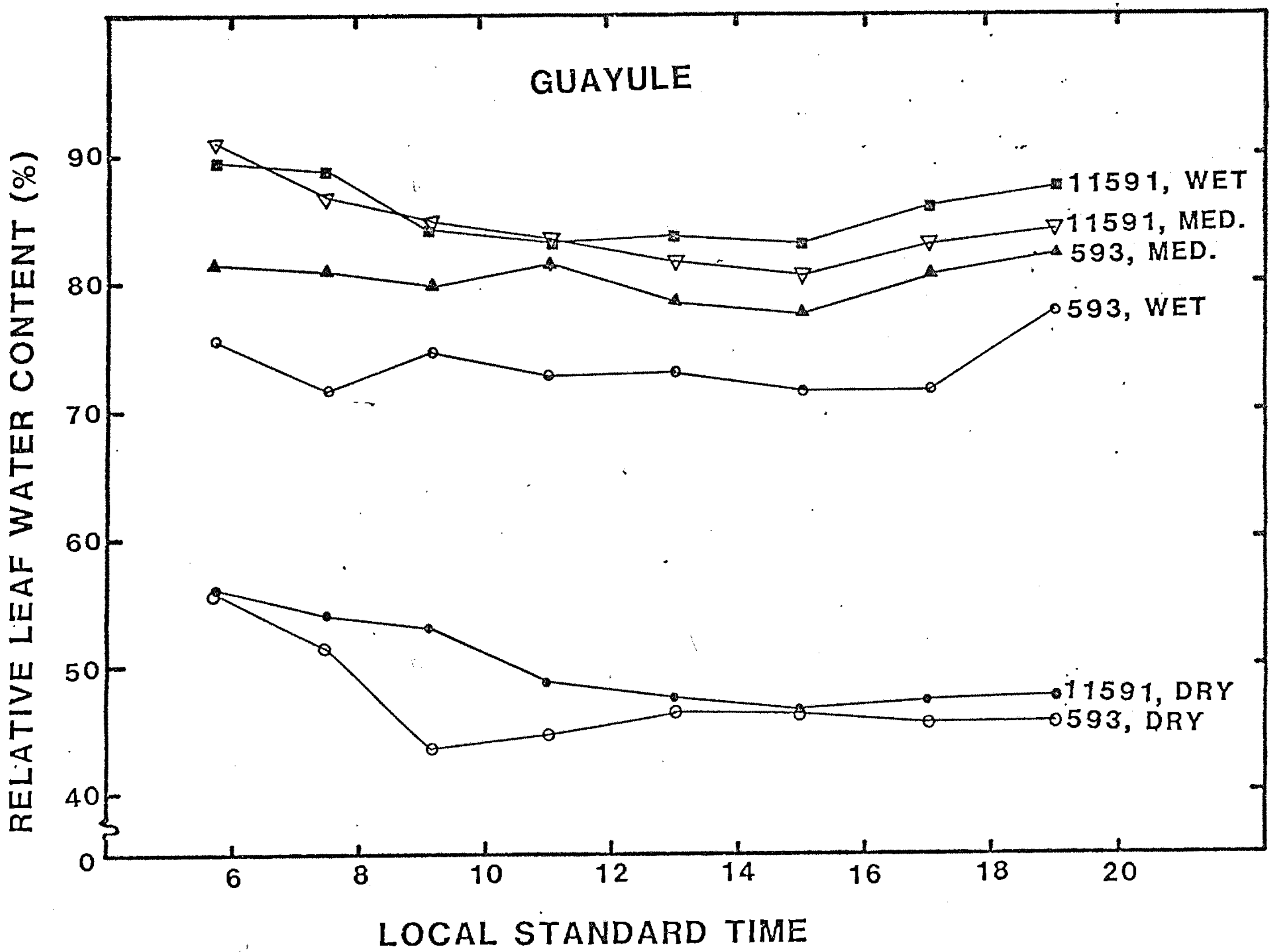

Fig. 1. Time course of water uptake by intact leaves of guayule cv. 11591 as influenced by initial leaf hydration.

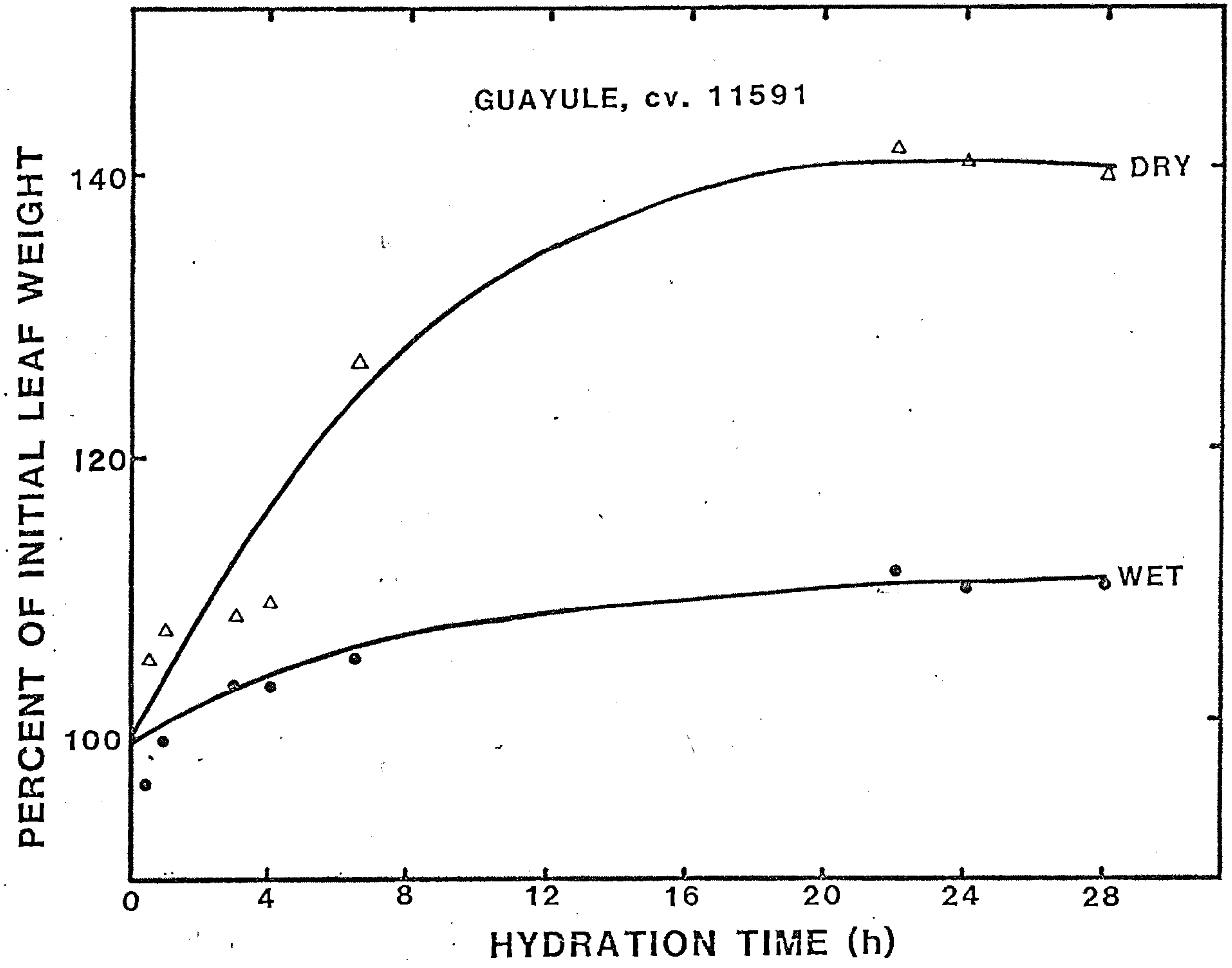

Fig. 2. Diurnal changes in the relative leaf water content of guayule cv. 11591 and 593 in relation to soil water content. The following amounts of water (mm) were present in 170 cm of soil: 11591 (wet), 348; 593 (wet), 301; 593 (med.), 274; 11591 (med.), 264; and both 11591 and 593 (dry), 180.

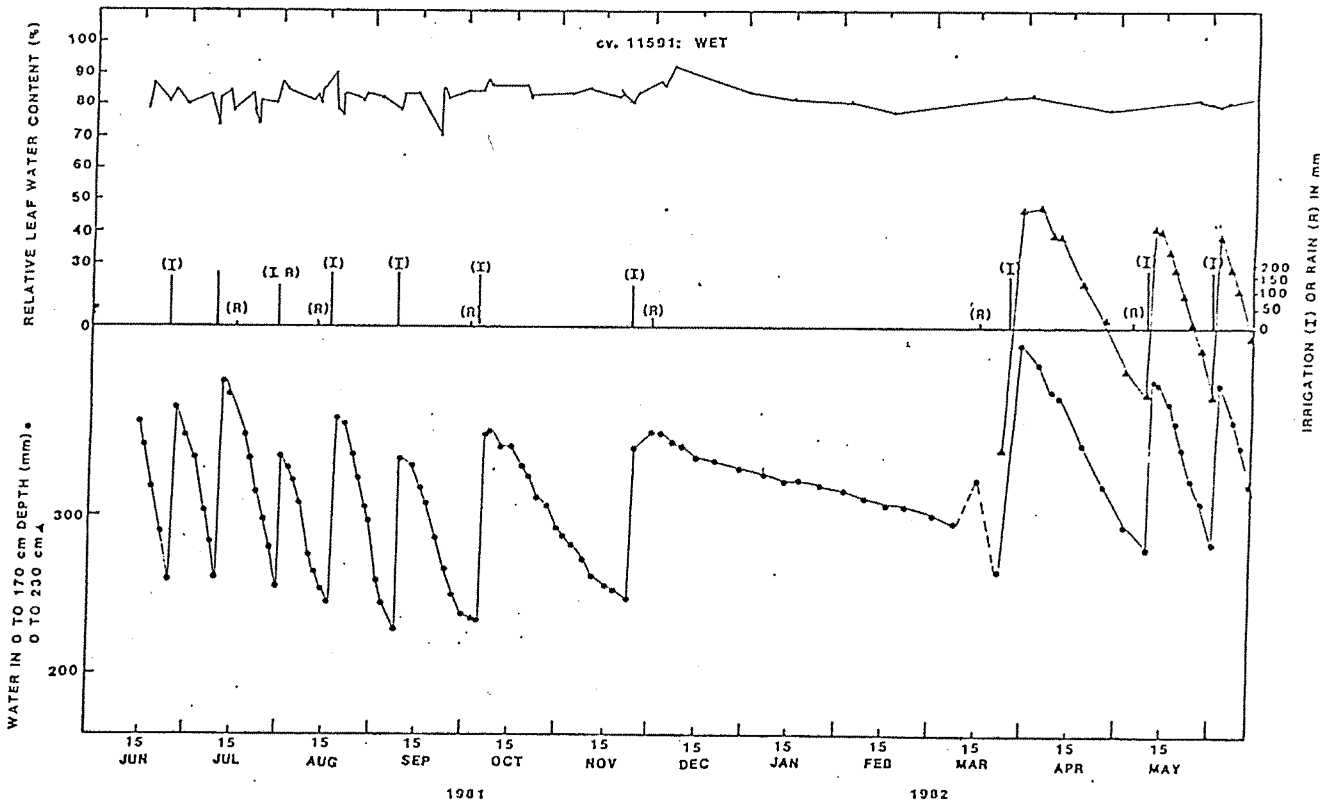

Fig. 3. The annual course of the relative leaf water content (RLWC) of guayule cv. 11591 and the amount of water in the soil profile (mm in 170 or 230 cm) in relation to irrigation and rainfall (mm), for the wet treatment (10 irrigations shown, but a total of 14).

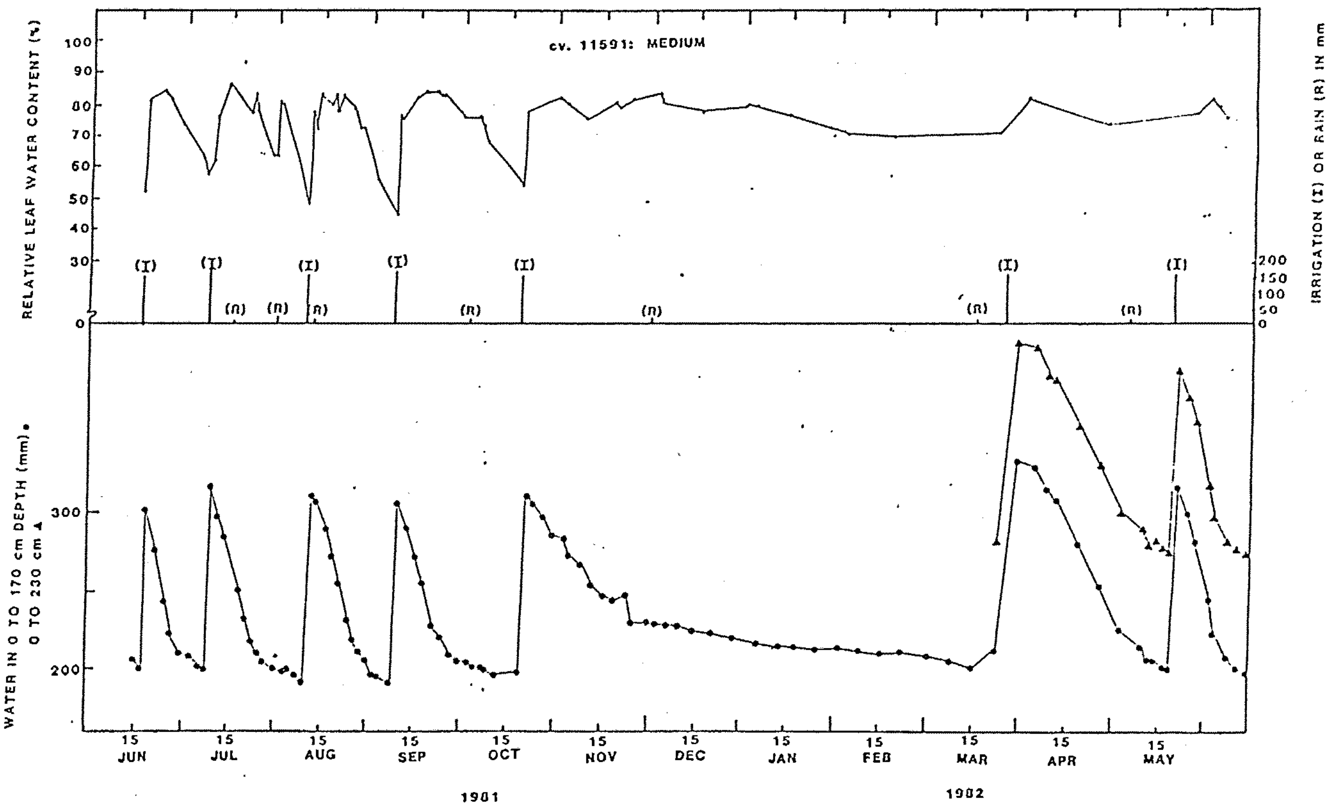

Fig. 4. The annual course of the relative leaf water content (RLWC) of guayule cv. 11591 and the amount of water in the soil profile (mm in 170 or 230 cm) in relation to irrigation and rainfall (mm). for the medium treatment (7 irrigations shown, but a total of 9).

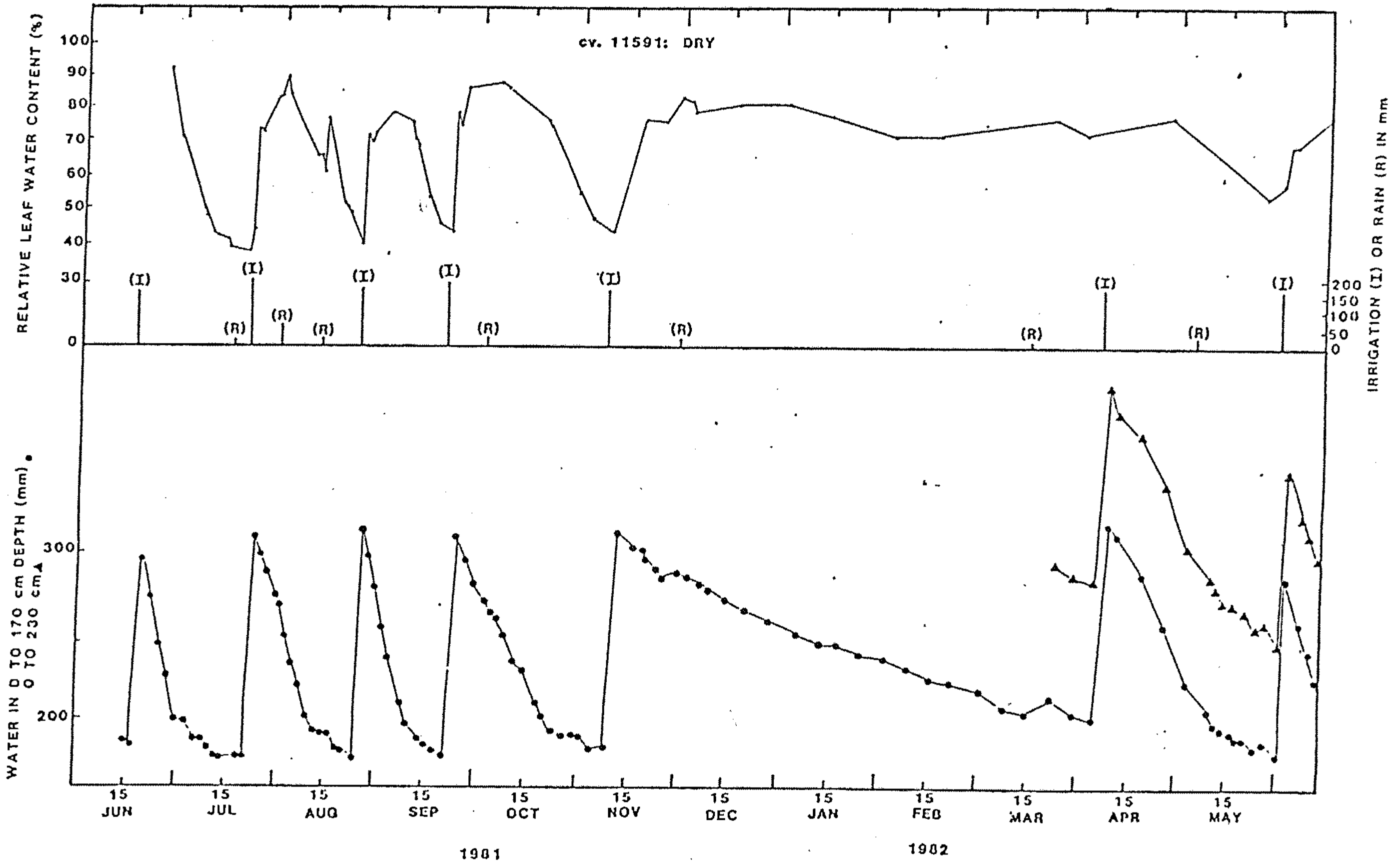

Fig. 5. The annual course of the relative leaf water content(RLWC) of guayule cv. 11591 and the amount of water in the soil profile (mm in 170 to 230 cm) in relation to irrigation and rainfall (mm), for the dry treatment (7 irrigations shown but a total of 8).

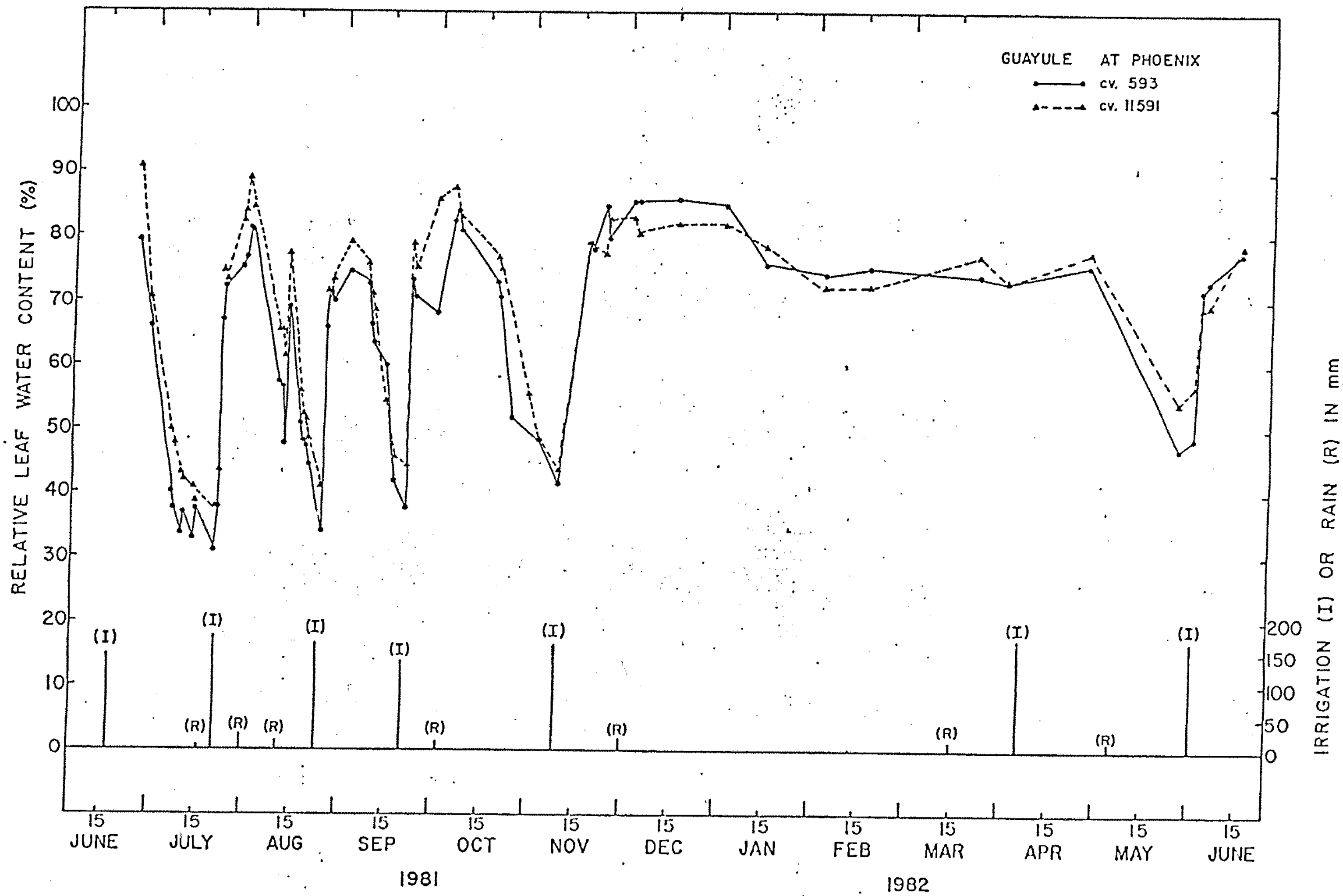

Fig. 6. The annual course of the relative leaf water content (RLWC) for the dry treatment of cvs. 593 and 11591 in relation to irrigations and rainfall.

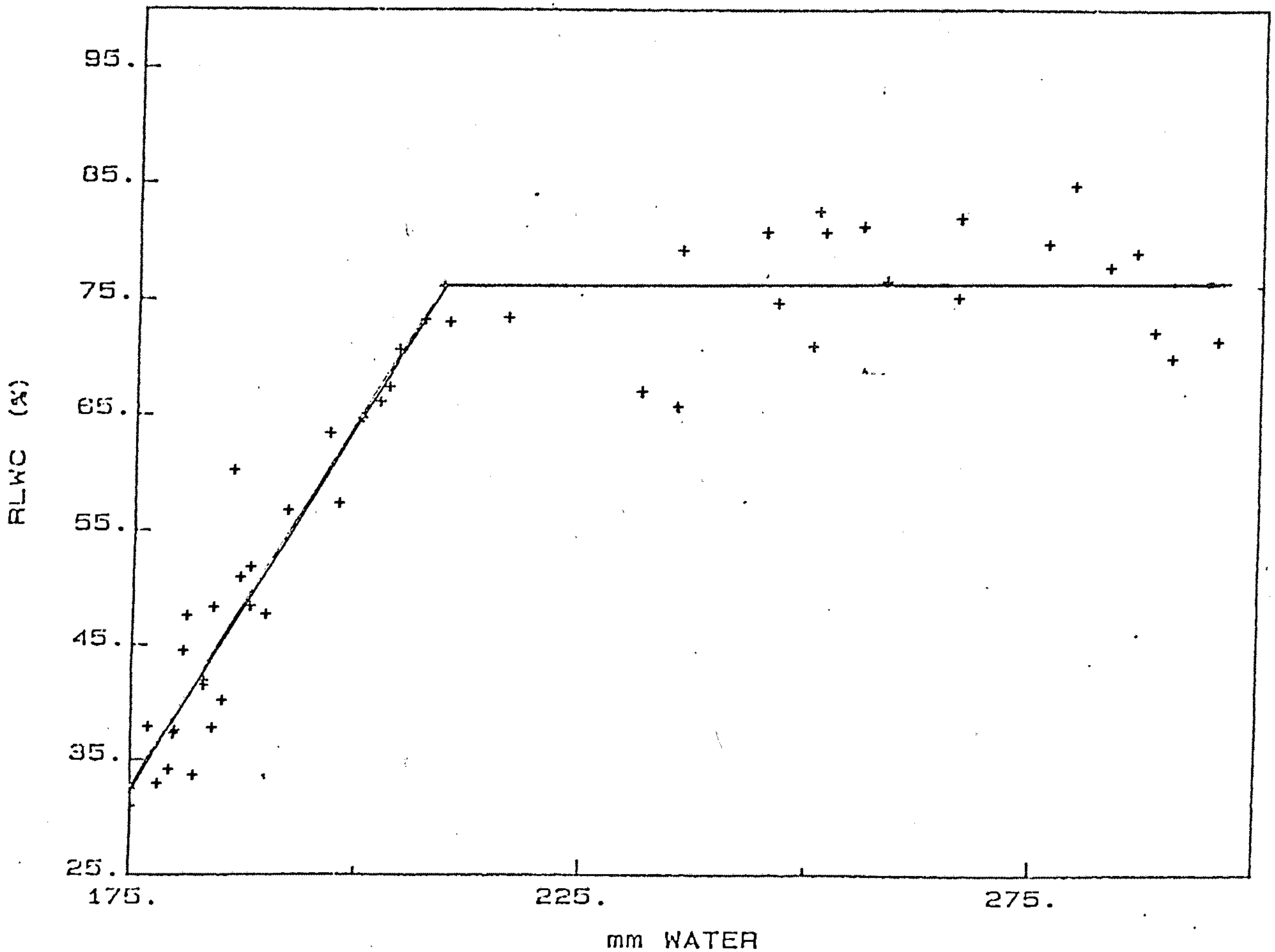

Fig. 7. The relation between the relative leaf water content (RLWC) and the amount of water in the soil (mm in 170 cm) for guayule cv. 593, <u>dry</u> treatment.

II. Water Use by Two Irrigated Guayule Cultivars in an Arid Climate

INTRODUCTION:

This research is in the fourth year at the University of Arizona Mesa Experiment Station. There are four levels of irrigation with two cultivars, 593 and N565-II.

PROCEDURE:

In March 1982, when the plants were 33 months old, they were cut off 10 cm above the soil line for rubber analyses, and allowed to grow back. Nitrogen fertilizer was applied at what is considered a high rate for guayule (150 pounds per acre, to stimulate rapid growth and recovery for a subsequent harvest). In order not to "burn" the plants, a heavy irrigation was given immediately after irrigation, and for several months thereafter the differences among treatments in regard to soil water stress were deliberately minimized for the same reason.

RESULTS AND DISCUSSION:

As shown in Table No. 1, there were significant differences among the treatments in the total number of irrigations and amount of water applied, but the most stressful treatment, No. 4, still was given slightly more water than during the previous year (388 versus 332 mm). There also was more rain in 1982 than in the prior year (15.2 versus 5.8 inches).

This experiment will help answer the question of when is the proper time to harvest guayule for maximum rubber production. Sometime in the next few months the plants will be harvested again for rubber analyses.

SUMMARY AND CONCLUSIONS:

This experiment is continuing into its fourth year. It is likely that commercial plantings will not be able to afford that long a period before obtaining a yield of rubber. This experiment and another more comprehensive one in progress now at the Mesa farm will help determine the optimum irrigation regime and growth period for rubber production.

PERSONNEL: W. L. Ehrler, D. A. Bucks, and F. S. Nakayama

Table 1. Treatment number description, number of irrigations, and the total amount of water applied [in addition to 304 mm (12.0 inches) of rain] to guayule cultivars 593 and N565-II at Mesa, Arizona in 1982.

Trt. No.	Description	No. of Irrigations	Total Water Applied mm	Total Water Applied inches
1	Wet	10	1305	51.5
2	Intermed.	10	1066	42.0
3	Intermed.	7	626	24.6
4	Dry	5	388	14.2

TITLE: VOLATILE COMPONENTS OF THE GUAYULE PLANT

NRP: 20740 CRIS WORK UNIT: 5510-20740-012

INTRODUCTION:

Preliminary results were reported on the determination of hydrocarbon emission from guayule plants in last years annual report. The emission of hydrocarbons by temperate zone plants has been known for a long time (Graedel, 1979) with the coniferous and deciduous forest most frequently associated with this phenomenon. The composition of such terpenoid volatiles is polyisoprene based and since isoprene is the basic unit of natural rubber and terpene related compounds in the resin fraction of guayule (Parthenium argentatum Gray), studies were initiated in 1981 to see whether isoprene and isoprene-related hydrocarbons are evolved by this arid-zone plant. For this objective we have attempted to identify the chemical composition and the emission rate of the hydrocarbon compounds. Such measurements would provide information on the hydrocarbon emission losses relative to rubber and resin production, and on the carbon balance of guayule in the ecosystem.

PROCEDURE:

Eighteen- to 24-month-old cultivar 11591, guayule plants were used in the study. Vapor samples were collected from single plants grown in field plots from an experiment being conducted for determining water-use and stress pattern of guayule, and included three irrigation levels. The "wet", and "medium," and "dry" irrigation treatments involved irrigation when 65, 80, and 95% of the available water in the 160 cm profile was removed.

Two methods of collection, a flexible transparent plastic cover and a rigid chamber, were used for collecting vapor emissions from the individual plants, approximately 60 cm tall by 45 cm wide. One procedure involved the use of a 54 cm wide x 90 cm high Teflon bag which could be lowered onto the plant. The bag was squeezed tightly at the stem-soil interface to minimize exchange between the inner air and the surrounding atmosphere. The sample air was circulated within the bag by a bellows pump system and samples collected into 6-liter stainless steel containers. Two to six minutes enclosure times were used. The method described by Zimmerman (1979) was followed in this initial sampling technique.

The alternate sampling technique was based on a sturdy plastic chamber made from Plexiglass, 45 cm x 47 cm wide by 81 cm high, which was equipped with a circulating fan. The motor was mounted outside the chamber to avoid possible ozone contamination from the electric motor. The soil surface around the plant was first covered with a thin piece of plastic film and stabilized with a rectangular frame onto which the chamber was placed. Air samples were collected with hypodermic syringes for CO_2 analysis, and the vapor emission collected in the steel containers as described with the bag sampling method.

The collected gas was passed through a condensation trap surrounded with liquid oxygen or nitrogen, and aliquots of the thawed material injecte into a gas chromatograph or mass spectrometer for total hydrocarbon emission and chemical composition determination. The carbon dioxide concentration was measured separately on an infrared gas analyzer. Emission and photosynthetic rates were based on the differences in concentratio between the blank sample taken just prior to enclosing the plant and the sample after a given exposure period.

Meteorological measurements including dry-bulb and wet-bulb temperatures, net radiation, and soil-water contents were made. Plant temperatures before and after enclosure were also taken.

RESULTS AND DISCUSSIONS:

Analyses of vapor emissions collected from the wet plot are listed in Table 1, based on an earlier report (Nakayama, et al., 1982.). Similar results were obtained in this study on the other irigation levels, but at different emission rates. The α- and β-pinenes made up the major portion of the volatiles, 50 to 30% of the total, respectively. Isoprene, on the other hand, was lower and in the order of 5% of the total volatiles.

From data available on similar types of analysis, the isoprene to α-pinene and β-pinene relations are different between the guayule and other plants. For Turkey oak (*Quercus laevis*) isoprene = 23.43, α-pinene = 0.37, and β-pinene = 0.15 mg/g/hr; and Live oak (*Quercus virginiana*) isoprene = 9.3, α-pinene = 0.05, and β-pinene = 0.06 mg/g/hr (Zimmerman, 1979). Other data available, where isoprene has been identified, indicate that isoprene emission is as high if not higher than the other hydrocarbon component emitted. Similarities and differences exist between the type of hydrocarbon emitted by guayule and other plants. For example, nine of the hydrocarbon compounds of Table 1, except isoprene and α-thujene were identified recently in redwood (*Sequoia sempervirens*) by Okamoto et al, (1981).

Other vapor analyses from samples collected at two different cycles in the three irrigation treatments are given in Table 2. In this instance, the various hydrocarbon constituents were totaled together. Emission rates for plants in the "wet" irrigation treatment, as noted by the fraction available water, were consistently higher than the "medium" or "dry" treatments. Emission rates increased following irrigation as shown in the lower half of the table. The dry treatment in particular showed a large increase. Presumably, the greater emission rate was caused by larger stomatal openings, but leaf resistance measured using the porometer was not made because the leaf size was too small to fit onto the leaf resistance meter.

An estimate was made on the total carbon lost to the atmosphere based on an emission rate of 10 mg/hr/plant at a plant density of 24,700 plants/hectare, 10 hr/day emission occurring for 100 days a year. A value of 0.23 metric T/Ha/yr was obtained. Admittedly, this is a very crude estimate and additional experimental measurements, such as diurnal determination on an annual basis, must be made for improving the number derived. Existing data on natural hydrocarbon emission from vegetation suggest that the organics are not likely to have significant effects on air quality (Bufalini, 1980). Predictions on the effect of intensive cropping of guayule on air quality cannot be made also until additional data are gathered. Instead of looking at any adverse condition developing, other positive effects can be a possibility. Blondell (1981) postulated that the lower cancer rates occurring in very rural areas might be associated with the emission of anticarcinogenic substances (isoprene as an agent) from local vegetation made up of oak and pine forests. Potential allergenic problems have been raised by Mears and Larson (1982) involving sesquiterpene lactones which are absent in existing varieties of guayule plants involved in rubber production. The amount of such lactone compounds contributing to the volatile components would be exceedingly small, and contact hazards would create the major problem.

When we look at the whole ecosystem for carbon balance an interesting picture can be developed for guayule rubber production. Theoretical maximum and measured ranges of photosynthesis for biomass production are summarized in Table 3, portions of which follows the report of Bassham (1977). Crops in the table include the C-3 alfalfa (Medicago sativa), sugarbeet (Beta vulgaris), and eucalyptus (Eucalyptus sp.), and the C-4 sugarcane (Saccharum officinarum), and sudangrass (Sorghum sudanense). The guayule whole-plant dry matter and rubber yields were derived based on an estimated rubber production of 560 kg/Ha/yr with 5% rubber content in the plant. These estimates appear to be reasonable based on the yields reported in the Emergency Rubber Project and some of our more recent findings. Rubber yields from Hevea are in the order of 890 Kg/Ha/yr (Bonner and Galston, 1947).

First, it is observed that the guayule plant is on the lower end of the scale as far as photosynthetic efficiency is concerned compared to other economic plants. The efficiency may be improved by a factor of two and possibly three by maximizing agronomic management and improving the genetic makeup of the plant. Yield comparison may be made also with other arid-land crops such as Russian thistle or tumbleweed (Salsola kali) which produces in the order of 10 metric T/Ha/yr dry matter under irrigation of 350 mm total water and fertilization (Hageman and Fowler, 1977). Approximately one-third or less of this yield was noted in natural stand with 200 mm rainfall in Arizona (Foster, et al., 1980).

The estimate also shows that the hydrocarbon emission can become a significant part of the rubber hydrocarbon retained in the plant. Tingey, et al., (1979) observed that 0.1 to 2% of the carbon fixed during photosynthesis could be accounted for by isoprene emission in live oak (Quercus virginiana). Whether that part of the hydrocarbon lost by the guayule could have contributed to rubber or resin content is an unknown. Possibly by genetic selection, chemical treatment or stress management, emission losses can be minimized for improving rubber production.

The first in the series of photosynthesis measurements made together with the hydrocarbon emission sampling is presented in Table 4. The plants in the unstressed wet irrigation treatment had the highest photosynthetic rates. These rates are within the range of the photosynthetic rate gi in Table 3. The values in Table 3 were converted to daily rates from yearly yield, whereas those in Table 4 were obtained for a specific da July-August period when photosynthesis is expected to be higher than t based on an yearly average.

SUMMARY:

The arid-adapted guayule plant behaves in a manner similar to the temperate-zone plants like oak and pine relative to hydrocarbon emissi There appears to be an interrelation between photosynthetic and hydroc bon emission rates, both of these probably being tied to stomatal conductance. Initial measurements and estimates indicate that hydrocar loss can make up a significant amount in relation to the rubber in the plant.

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PERSONNEL: F. S. Nakayama

Table 1. Volatile hydrocarbon compounds identified from guayule includ emission rates (μg/g leaf biomass/hr)

	Plant	
Compound	A	B
Unidentified	0.009	0.008
α-thujene	0.021	0.005
β-phelladrene	0.012	0.007
α-phelladrene	0.028	0.031
Sabinene	0.050	0.036
Ocimene	0.070	0.101
Myrcene	0.096	0.063
Camphene	0.222	0.192
Isoprene	0.340	0.210
Limonene	0.493	0.434
β-pinene	1.834	1.459
α-pinene	3.621	2.745

Table 2. Effect of irrigation levels on hydrocarbon emission rates

IRRIGATION LEVEL	Θ_F	EMISSION RATE (mg/hr/plant)
Wet	0.36	26.7
Medium	0.09	4.7
Dry	0.15	3.0
Wet[a]	0.59	30.9
Medium	0.08	3.1
Dry[a]	0.31	12.0

a/ Plots irrigated two days before sampling.

Θ_F = fraction available water remaining in the 170 cm depth increment.

Table 3. Estimated photosynthetic productivity of crops and hydrocarbon emission losses of guayule

ESTIMATES	$g/m^2/d$	Metric T/Ha/yr
1. Theoretical maximum Southwest U.S. (dry matter)	90	325
2. Measured ranges		
(dry matter)	10 - 30	36 - 110
(carbon equivalent)	4.4 - 13.3	16 - 48
3. Guayule, whole plant		
(dry matter)	3.2	11.8
(carbon equivalent)	1.4	5.2
4. Rubber		
(dry matter)	0.20	0.60
(carbon equivalent)	0.18	0.53
5. Hydrocarbon emission		
(carbon equivalent)	0.08	0.23

Table 4. Estimated photosynthetic rate for guayule under different irrigation treatments[a]

	Irrigation Treatment			
	Wet	Medium	Dry	Reported range other plants
Photosynthesis				
(kg-C/Ha/d)	56	38	8.4	45 - 135
(lb-C/Ac/d)	50	34	7.5	40 - 120

[a] Based on a 12-hour day; 24,700 plants per Ha.

TITLE: RUBBER AND RESIN ANALYSIS IN GUAYULE 1982

NRP: 20740 CRIS WORK UNIT: 5510-20740-012

INTRODUCTION:

Developmental procedures followed for the analysis of resin and rubber in the guayule plant were discussed in the 1981 Annual Report. Other locations involved in guayule production analysed samples provided by this laboratory to compare procedures. Statistical analyses of the results are to be made by the ARS Eastern Utilization Laboratory at Peoria, Illinois. The Vegetable and Fruit Chemistry Laboratory in Pasadena, California, cooperated with this laboratory in the initial phase of interlaboratory comparisons of rubber analysis.

PROCEDURE:

The acetone-cyclohexane extraction method we developed earlier was used to analyze resin and rubber in various randomly selected guayule samples (Annual Report 1981 and Black et al., 1982). The nuclear magnetic resonance (NMR) method of Hayman et al., (1982) was applied to the same set of samples.

RESULTS AND DISCUSSION:

The analytical results from the two different methods of rubber analysis are presented in Table 1.

The Wilcoxon paired-sample and the t-test, when applied to this set of data, show there was no difference between the two analytical methods, i.e., the procedures give the same results. The advantage of the extraction method is its cost, since it is much cheaper than the NMR method by several orders of magnitude.

SUMMARY AND CONCLUSIONS:

Interlaboratory comparison of the solvent extraction and nuclear magnetic resonance techniques shows similar results. Since the extraction method is much cheaper than the NMR technique, more frequent use will be made of this method, with the assurance that the analytical procedure is reliable.

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PERSONNEL: F. S. Nakayama, B. A. Rasnick

Table 1. Comparison of rubber analyses based on the acetone-cyclohexane and nuclear magnetic resonance methods.

Sample No.	Acetone-Cyclohexane	NMR	:	Sample No.	Acetone-Cyclohexane	NMR
6B	6.16	6.15	:	21B	7.12	7.95
6D	5.44	5.50	:	21D	9.64	8.15
7C	2.39	2.39	:	22B	5.64	6.05
7C	2.54	1.95	:	30F	6.01	6.55
8B	3.15	2.50	:	24B	7.18	7.20
8D	4.00	4.20	:	24E	6.41	4.90
9A	5.37	4.70	:	25B	6.71	4.55
10A	3.64	4.00	:	29A	8.83	8.75
10A	3.66	3.95	:	29A	9.88	8.80
10B	2.59	3.10	:	29C	8.39	7.75
10E	3.92	4.35	:	31D	8.29	7.85
18B	7.45	6.90	:	31D	7.92	7.90
19D	4.05	5.35	:	32C	6.12	5.50
19D	4.39	5.45	:	32F	3.70	3.95
21A	6.71	7.10	:	32F	3.44	3.80

TITLE: DIRECT SEEDING FOR ECONOMICAL GUAYULE RUBBER PRODUCTION UNDER DIFFERENT CLIMATIC AND SOIL CONDITIONS

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

INTRODUCTION:

The economical feasibility of guayule production depends largely upon the method of stand establishment. In the past this has mainly been achieved through transplanting of nursery-grown plants into the field; and more recently, greenhouses have been used for growing seedlings. Costs of field nursery or greenhouse production and transplanting are significant factors in terms of the overall production scheme. The development of economical direct seeding techniques could greatly improve upon the economics of guayule commercialization (Foster, et al., 1980).

The wartime Emergency Rubber Project (ERP) of the U. S. Department of Agriculture, from 1943 to 1946, conducted a number of direct seeding trials throughout the southwestern United States. The results of these trials indicated that direct seeding would be feasible only under certain management and environmental conditions. For example, Hansen (1944) planted both dry and pregerminated guayule seed with variations in irrigation treatments and planting depths. The soils consisted of loamy fine sand and sandy loam which were preirrigated to field capacity. Surface irrigations were applied almost daily from the time of sowing to emergence. At least five subsequent irrigations were necessary in the first month. Emergence was general, regardless of treatment, but results were best where sowing was shallow and covering was uniform. Windstorms damaged the fall plantings, and severe rainstorms damaged the spring plantings. Damping-off diseases (possibly Fusarium, Rhizoctonia, or Phythium) affected survival for spring plantings under himid conditions. The guayule plantings on the lightest soils were considered failures and costs of direct seeding were considered more expensive than transplants of nursery grown plants (Hammond and Polhamus, 1965).

There was considerably more success with trials in Indio, California, in September and October 1943 (Hammond and Polhamus, 1965). Pregerminated and dry seed were sown on Coachella sand at a rate of 17 kg/ha (15 lbs/acre), although a much lower rate could have been used. A side-dressing of nitrogen fertilizer at a rate of 280 kg/ha (250 lbs/acre) was used, which later proved to be beneficial (Haise, 1945). Following the initial irrigation, surface irrigations were given every other day to a total of six irrigations. Good emergences from the pregerminated seed occurred after 3 to 4 days and 5 to 7 from the dry seed. The use of dry seed in this trial was as satisfactory as the pregerminated seed. It was noted that plantings made in late October resulted in poor stands due to low soil temperatures which dropped below 10°C (50°F). Fall planting of seed appeared to be better suited than spring planting for Indio because of the high winds and frequent rainfall (Haise, 1945).

Other experiences were similar during ERP. Taylor (1946) specified the need for adequate moisture without soil crusting during germination and emergence. Again, seeds should be started when soil temperatures are above 10°C (50°F) and placed at very shallow 0.5-cm (<0.2-in.) depth. Interactions were observed between irrigation frequency and depth of seed placement (Tingey, 1943). Better germination was obtained using frequent irrigations and a 0.6-cm (0.25 in.) soil depth. Similar yields were obtained with direct seeding and transplants, but the possibility exists for shortening the cultivation period by direct seeding (Tingey and Clifford, 1946).

Besides the problems of seed germination, guayule seedlings are slower growing compared with weeds and will not compete with them. Slow growth also makes the plants susceptible to insect and plant diseases. Davis (1945) demonstrated at Poston and Yuma, Arizona, that an adequate stand could be obtained with direct seeding, a fall planting took place in October 1943 on Superstition fine sand. Problems arose from high temperatures and sandstorms. The instability of the sand caused problems in handling surface irrigation without eroding or flooding. Although the plants grown in this study were never lacking in water, the stand obtained by direct seeding was better than achieved by transplants.

Before the initiation in 1982 of direct seeding trials under field conditions similar to Davis in 1943, investigations were begun by Dr. G. R. Chandra, Chief, Seed Research Laboratory, Beltsville, Maryland, with the essential objectives to understand the natural type of dormancy in selected guayule strains and to develop a seed conditioning technology for the preservation and enhancement of germination and vigor of guayule seeds. The overall strategy is to develop a cleaning/conditioning technology wherein by anaerobic and aerobic fermentation procedures, the seed is freed from the sterile florets and the redox potential of the seed can be regulated in order to preserve its viability and enhance its germination. Our objective is to develop improved techniques for direct seeding with conditioned and unconditioned seeds under adverse field conditions.

FIELD PROCEDURES:

The initial direct seeding experiment was planted on November 4 and 5, 1982, at the Yuma Mesa Experiment Station on Superstition sand (91 to 94% calcareous sand). Four planting practices included: (1) conditioned seed; (2) pelleted seed; (3) raw (or dry) seed; and (4) fluid drilling of imbibed seeds. Each practice was planted in two areas; one-half with fungicide incorporated into the soil, and the other one-half without fungicide prior to planting. The fungicide used in this trial was Terrachlor Super X (pentachloronitrobenzene, (10%), plus 5-ethoxy-3-trichloromethyl-1,2,4 thiadiazole, (Olin Corp.), which is a combination of Terrachlor for Fusarium and Rhizoctonia problems and Terrazole for Pythium control at low rates. Based on greenhouse studies by Dr. S. M. Alcorn, Plant Pathologist, The University of Arizona, Tucson, Arizona, a non-phototoxic rate of 146 kg/ha (130 lbs/acre) was recommended for this initial investigation. A total of 15 rows, spaced 54 cm (21 in.) apart, were planted in the bottom of a small corrugation 7.5 cm (3 in.) deep to accommodate the sandy soil condition and to possibly reduce damage by sandstorms. Row lengths were 152 m (500 ft) long. The conditioned seed was planted at 10 seeds/m (3 seeds/ft); the pelleted and raw seeds at 79 to 92 seeds/m (24 to 28 seeds/ft); and the fluid drilled seeds at 66 to 79 seeds/m (20 to 24 seeds/ft). The field planting diagram is given in Figure 1.

The conditioned seeds were primed by the Seed Research Laboratory, using a priming solution consisting of 20% (W/V) polyethylene glycol (PEG) from Sigma Chemical Co. (mol. wt. 6000) 0.1% (W/V) Thiram (DuPont Chemical Co., fungicide), 10^{-3}M gibberellic acid (GA) from Sigma Chemical Co.), and pH adjusted to 8.0 with 0.2 m $CA(OH)_2$. Laboratory results showed that the primed seeds should remain in the primary solution in total darkness (light excluded by placing dishes in black cloth bags) until prepared for shipment. There were two groups of seeds primed for this initial direct seeding trial on different dates: On October 13, 1982, the primed seeds were immediately placed in the black bags; whereas on October 15, 1982, the primed seeds were exposed to light for a period of time before being placed in darkness. Laboratory studies showed that the bulk seed used on this study with an initial germination of 30-33% could be increased to 60-66% with the PEG and GA treatment when exposed to proper light and moisture. In the field, test tubes with three seeds in a micromix x 200 (pearlite, vermiculite, and peat moss) remained in total darkness before planting. A small hole (about 1.0 cm deep x 0.5 cm diameter) was made with a gauge in the sandy soil followed by emptying the contents from the test tubes into the hole where the seeds were buried at a depth of less than 0.5 cm (0.2 in.).

The pelleted and raw seeds were both planted at the same rate and again at a depth of less than 0.5 cm (0.2 in.). A standhay planter with rubber belts was used to plant the pelleted seed, and a John Deere cone planter was used to plant the raw seed. The pelleted seed was split-coated bulk seed by Royal Sluis with an initial germination of 30-33%. The raw (dry) seed was cleaned, threshed and untreated with sodium hypochlorite of cv. N565-II and bulk variety. The Cv. N565-II seed had a laboratory germination of 35-37%. Both were planted on November 4. A light seed cover (less than 0.3 cm) of vermiculite was used on rows 3, 4, 9, 10, 11, 12, 13, 14, and 15 (Figure 1).

The fluid-drilled seeds, cv. N565-II and bulk, were imbibed (partially pregerminated) starting on the morning of November 4. For a 24-hour period, the seeds were placed in an aerated water bath where the water was changed periodically as needed. In the early morning of November 5, the imbibed seeds were placed in a Laponite 445 gel. A fluid driller then was used to distribute the gel on the soil surface along with a light cover of vermiculite. Immediately after the fluid drilling, a light sprinkler (mist) irrigation using an automated lateral-move sprinkler system was applied. Overhead mist irrigations continued daily for eight days following planting and approximately two times per week throughout the remainder of the trial. The plants were fertilized four times with nitrogen at about 20 kg/ha (18 lbs/acre) through the sprinkler irrigation, beginning November 30 and lasting through December. Stand counts were taken following emergence by counting the number of plants per row in a 15.2-m (50 ft) length. These counts were taken at two week intervals to the end of December. Seedlings were sampled on December 30 for disease analysis by Dr. S. M. Alcorn, Plant Pathologist.

RESULTS AND DISCUSSION:

The conditioned (test tube) seed was the first to emerge on November 8 and 9, three to four days following planting. The fluid-drilled seed began to emerge on November 10, five days after planting. The pelleted and raw seed emerged on November 13 and 14, eight to nine days after planting. All planting methods followed the same type of curve for percent emergence. Figures 2 and 3 show the percent plant emergence for the first two months after planting for N565-II and bulk seeds, respectively. In all cases, there was a general drop in the rate of plant establishment after 20 to 30 days, and then a leveling off period.

The conditioned seeds with PEG and GA demonstrated the highest rate of emergence throughout the experiment (Figure 3). A sudden drop, however, occurred in the no-fungicide plot with the seeds primed on October 13. The conditioned seeds primed on October 13 in the fungicide-treated plot had a much higher emergence than any other treatment, including the seeds primed on October 15. Proper procedures were used for priming the October 13 seeds as discussed under field procedures and exhibited in the field data (Figure 3). With the Terrachlor Super X fungicide, the properly conditioned seeds showed a maximum percent emergence of 62% after one month and final percent emergence of 34% after two months. The maximum stand counts in the field agreed very closely with the maximum germination percentage in the laboratory, and the final stand counts were nearly the same as the original germination percentage for the bulk unconditioned seed. This was the only treatment where an acceptable stand was achieved in the opinion of the researchers.

The pelleted and raw seed were not significantly different from each other in both the fungicide-treated or non-fungicide treated plots and with the bulk seed. Average percent emergence after two months was between 13 and 16% (Figure 3). With the fluid drilling, the percent emergence appeared to be less for the bulk compared with N565-II seed (Figures 2 and 3). However, throughout the experiment, the percentages for the fluid-drilled seed and raw seed were comparable. The fluid-drilled N565-II seed on the fungicide treatment had a 17% stand count after two months, which was about one-half the original laboratory germination of 35-37%. Even though stand counts on the pelleted, raw, and fluid-drilled seeds averaged between 10 to 15 plants/m (3 to 4.5 plants/ft), there was not the necessary uniformity in the seedling distribution to consider that an adequate stand was achieved in two months

Table 1 shows that a total of 193 mm (7.6 in.) of water was applied through the lateral-move sprinkler system, which was nearly the same as the 192 mm of Class A pan evaporation for the two-month period. All indications were that adequate moisture was available to the seedlings and overirrigation or aeration would not have been a problem on the sand. Air and soil temperatures, however, may have been a factor since air temperatures averaged a maximum of 21°C (73°F) and a minimum of 6°C (43°F) (Table 1). Precipitation, totaling 39 mm (1.5 in.), and associated high winds on 9 and 10 December were also undoubtedly detrimental to the plant survival for the slow-growing guayule seedlings. The disease analysis of plants sampled on December 30 showed that every seedling was infected with Rhizoctonia, and some of them had contacted Fusarium. The disease problem occurred both on the original fungicide-treated plot as well as the non-fungicide-treated plot. The field was cleared on 10 January 1983, in order to prepare the soil for a second direct seeding trial in early spring.

SUMMARY AND CONCLUSIONS:

An initial direct seeding experiment was conducted using guayule seed that was specially conditioned, pelleted, raw, and fluid-drilled on Superstition fine sand at Yuma, Arizona. The conditioned seeds with polyethylene glycol and gibberellic acid resulted in the highest germination rate where the final field stand counts were nearly the same as the laboratory germination percentage for the unconditioned raw seed. The main problems in obtaining a uniform stand with this November seeding were cold temperatures, heavy rains in early December, and Rhizoctonia seedling diseases. Planting methods and irrigation practices used to obtain seed emergence were not a problem.

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PERSONNEL: D. A. Bucks, D. A. Dierig (U. S. Water Conservation Laboratory); G. R. Chandra (U. S. Seed Research Laboratory); R. A. Backhaus (Arizona State University; and R. L. Roth and S. M. Alcorn, University of Arizona).

Table 1. Biweekly water applications, precipitation, Class A pan evaporation, average maximum and minimum temperatures, and nitrogen applications on direct seeding trial, Yuma, AZ, 1982.

Date	Water applied (mm)	Precip. (mm)	Class A Pan Evaporation (mm)	Average Air Temp. °C Max.	Average Air Temp. °C Min.	Nitrogen Application (kg/ha)
05-06 NOV	43	0	33	27	7	
07-13 NOV	42	1	17	21	6	
14-20 NOV	20	6	21	22	8	
21-27 NOV	20	0	24	21	8	
28 NOV-04 DEC	12	3	18	21	5	21
05-11 DEC	18	39	19	21	7	22
12-18 DEC	20	0	15	21	5	17
19-25 DEC	0	0	21	19	5	22
26 DEC-01 JAN	18	0	24	15	2	
Total or Average	193 (7.6 in.)	49 (1.9 in.)	192 (7.6 in.)	21 (70°F)	6 (43°F)	82 (73 lbs/ac)

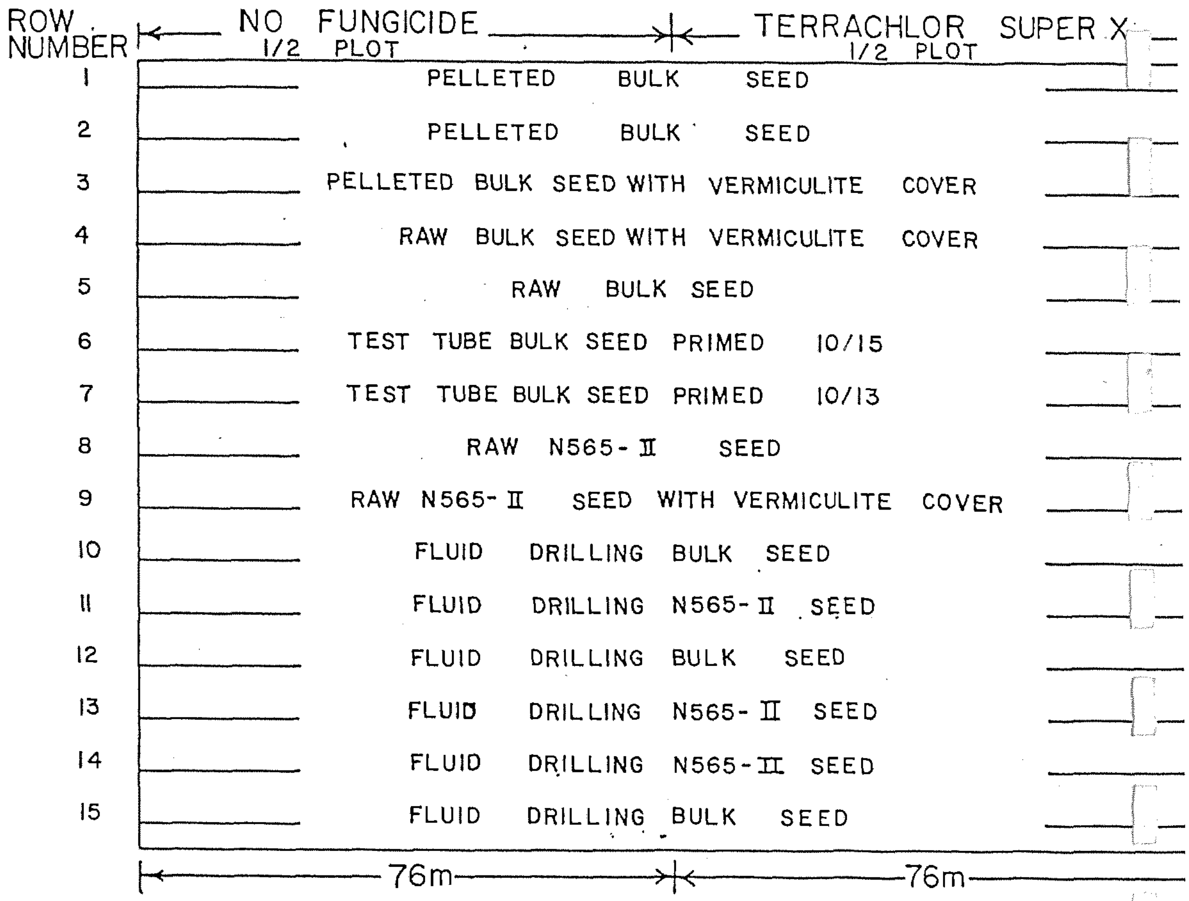

Figure 1. Diagram of direct seeding experiment on guayule at the Yuma Mesa Farm, November-December 1982.

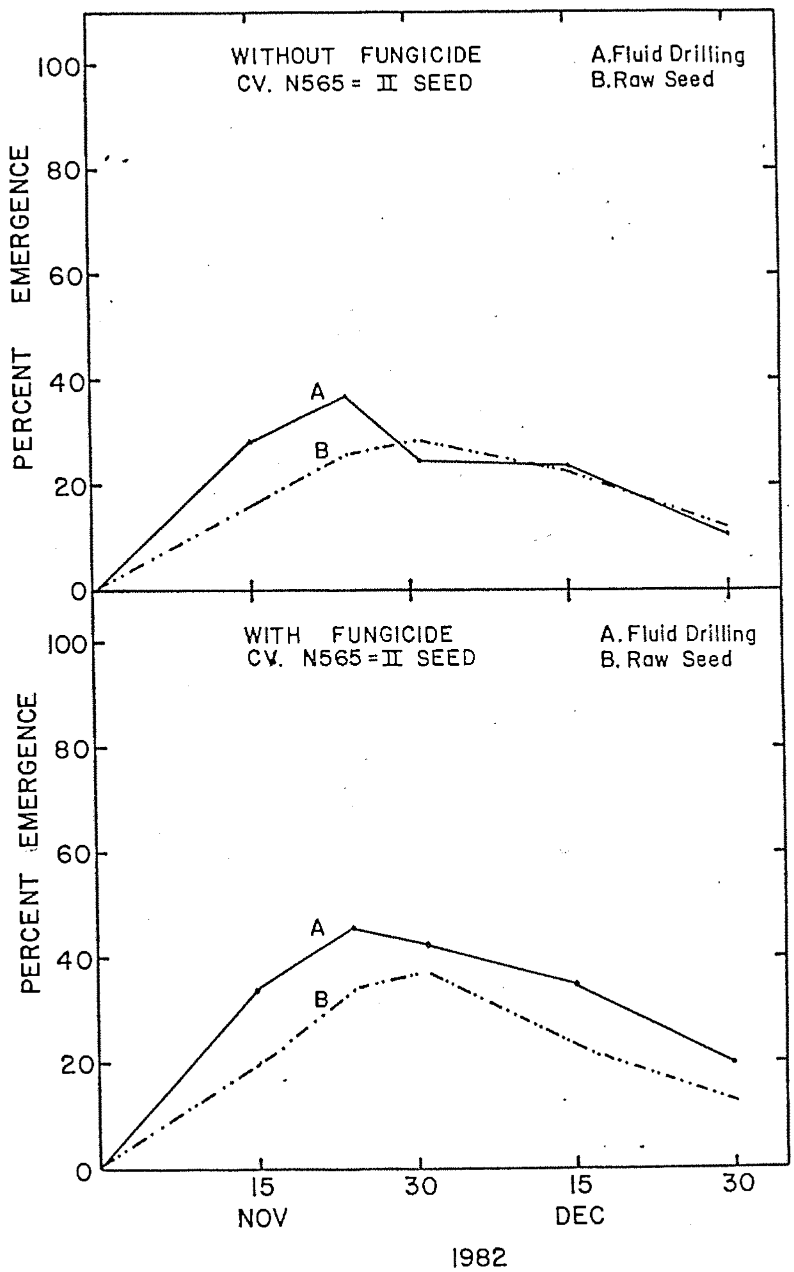

Figure 2. Percent emergence for two planting methods using N565AII guayule seed, November-December 1982.

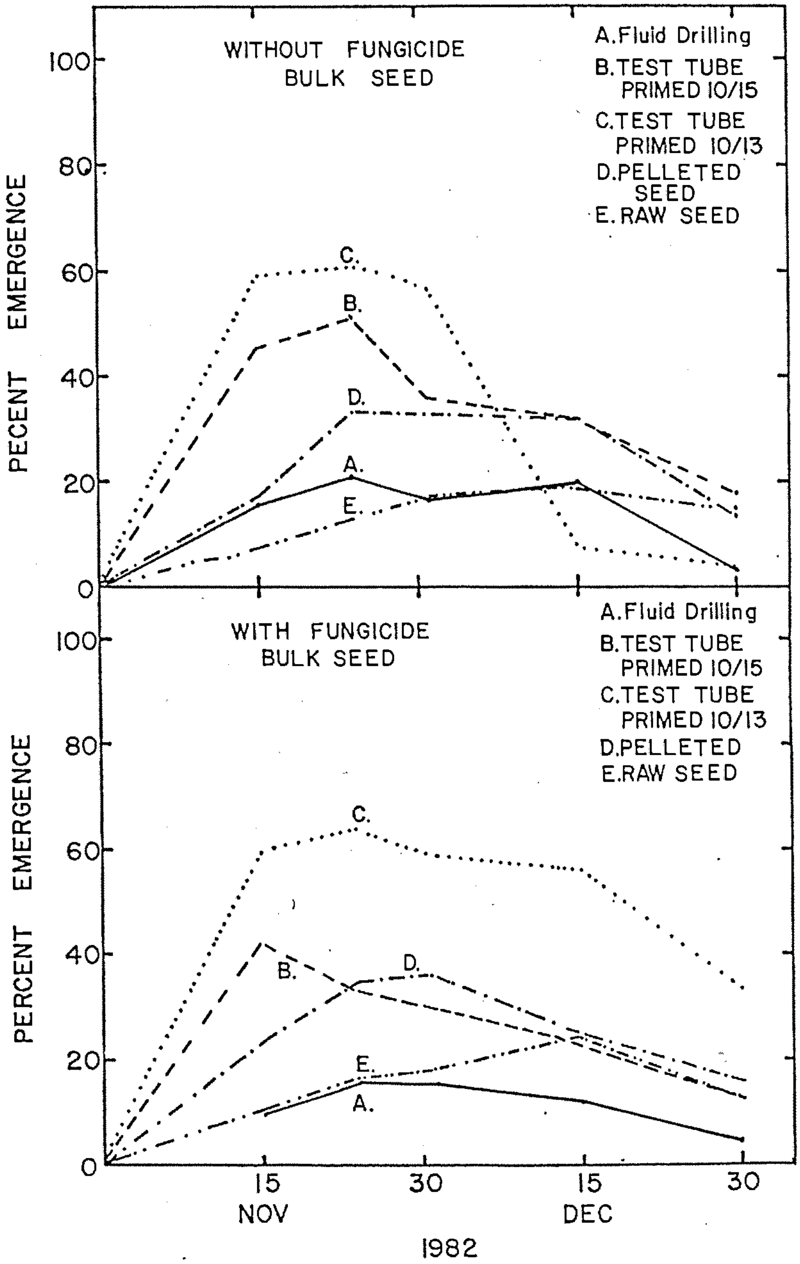

Figure 3. Percent emergence for four planting methods using bulk guayule seed, November-December 1982.

TITLE: RUNOFF-FARMING FOR DROUGHT-TOLERANT CROPS IN ARID ENVIRONMENTS

NRP: 20760 CRIS WORK UNIT: 5510-20760-002

INTRODUCTION:

This project, started in 1978, has the objective of determining the feasibility of growing a high-value crop, Christmas trees, successfully in an arid climate using only runoff farming to supply the needed supplemental water.

PROCEDURE:

For more details, see the annual reports from previous years. Briefly, measurements were made on the plots at both the Sandy Site and the Clay Site at Camp Verde on an approximately monthly basis. These periodic measurements consisted of monitoring rainfall, runoff, soil moisture, tree height, relative leaf water content, plant water potential (only on Arizona cypress), and tree survival; they were supplemented with a year-end measurement of trunk diameter and the second harvest of Christmas trees (all from the Quetta pine plot at the Clay Site).

RESULTS:

I. Sandy Site.

A. Quetta pine.

1. Volumetric soil water content. In general, soil water content (Θ_v) for all six plots gradually decreased from a maximum near the beginning of April to low values on 10 August, before increasing again for a short time, only to decrease to the minimum for the year on 30 August (Fig. 1). Then the rains caused Θ_v to increase up until the last measurement on 24 November. Fig. 2 shows this more clearly. Θ_v was quite similar in plots S-1 and S-3, even though the catchment of the latter was three times as wide as that for S-1. Plot S-2 was significantly lower in water content for the whole season, an anomalous response.

2. Relative leaf water content (RLWC). The RLWC of plots S-3 and S-1 was maintained at values which seem to indicate little or no stress (Fig. 3), i.e., above 80% for the whole season, with a tendency for S-3 to have somewhat higher values than S-1 for short periods. However, the RLWC of S-2 was much lower than that of S-1 and S-3 for about half of the growing season.

3. Height. As shown in Fig. 4, height growth began in early April and lasted until late November, the date of the last measurement. The growth rate was most rapid in S-3, which considerably exceeded that of S-1, and was least in S-2. The growth curves are almost parallel for S-1 and S-2, but the curve for S-3 is steeper and shows steady growth throughout the season.

4. Trunk diameter. This parameter was measured annually. Trunk growth was similar among the three treatments from 1979 to 1981, but in 1982 the rate for S-3 accelerated over that for S-1 and S-2.

B. Arizona cypress.

1. Volumetric soil water content. Θ_v was in proportion to the catchment width, i.e., highest on S-6, the widest catchment, next highest on S-5, the catchment with intermediate width, and lowest on S-4, the one with the narrowest width. This proportionality can be detected with some difficulty in Fig. 1 but with ease in Fig. 5. However, the extra amount of water in plot S-6 over that in plot S-5 was not very much when considering that 50% more rainfall-runoff should have been delivered to S-6 than to S-5. On the other hand, evidence that augmentation of rainfall was functioning was the considerably greater level of Θ_v in plots S-5 and S-6 over that in S-4 over the whole season.

II. Clay Site.

A. Quetta pine.

1. Volumetric soil water content. Θ_v was very high in late March (Fig. 6), being 0.25 even in the treatment with the narrowest catchment, C-1. Θ_v decreased abruptly from the peak to a low of around 0.1 in early November, and then started to rise again. Θ_v for treatments C-2 and C-3 was successively higher than C-1 at any given point along the whole seasonal curve.

2. RLWC. Catchment width was only moderately effective in raising the RLWC (Fig. 7). In general, the RLWC stayed at values above 80%, except for late May, when C-1 dipped to [illegible]%.

3. Height. Despite the rather small differences in RLWC among treatments, height growth of the pines was markedly different. Treatment C-2 began the year significantly ahead of the others and stayed ahead for the whole season (Fig. 8). Also, it is noteworthy that C-3, which had more water in the soil and was slightly higher in RLWC than C-1, grew less well for most of the season.

4. Trunk diameter. The growth in trunk diameter over three years showed C-2 to be best and C-3 the worst, consistent with the height data in Fig. 8.

B. Arizona cypress.

1. Volumetric soil water content. Θ_v peaked in late March at around 0.22 cm^3/cm^3 (Fig. 9), a value somewhat below the peak exhibited by the pine trees at the clay site. However, the

subsequent decrease was not so precipitous. Θ_v was in proportion to catchment widths, which is evidence for the functioning of the system according to design.

2. RLWC. The RLWC was considerably lower in Arizona cypress than in the Quetta pines (Fig. 7), and, within species, differences among treatments were small. Toward the end of July the RLWC of Arizona cypress decreased to minimal values that may have been an expression of water stress, 60-65%, but then rose in response to rain in September.

3. Height. Growth was similar among the three treatments until July (Fig. 10). The apparent approximately 3% decrease in height shown by the August measurements undoubtedly can be attributed to experimental error (such as swelling or shrinking of the soil at the base of the tree used for the reference for height measurements), and could be eliminated by smoothing the curve. However, it does indicate a definite slowing in the growth rate that concides with the low values of Θ_v at that time (Fig. 9) and the lowest RLWC reading of the season (Fig. 7).

4. Trunk diameter. During the period from 1979 to 1982, increases in trunk diameter were in proportion to the catchment widths, but the differences were not great.

III. Site comparison.

A. Volumetric soil water content. Θ_v for the Quetta pines was high in early spring at both the Sandy and Clay Sites (Fig. 11), but decreased sharply from April to May. This decrease continued more strongly at the Clay than the Sandy Site. Θ_v for the Arizona cypress at the Clay Site stayed at considerably lower levels than for Quetta pine for most of the growing season, i.e., until the values concided at the low Θ_v of 0.12 cm^3/cm^3 in October and November. This difference may be a reflection of a greater leaf area index or a higher transpiration rate in the Arizona cypress than in the Quetta pine. Θ_v (the mean of the three catchment widths) at the Sandy Site (pines) remained near 0.20 cm^3/cm^3 all through the summer and into the fall, whereas at the Clay Site it steadily decreased, falling to around 0.12 cm^3/cm^3 by November, before starting to rise with the fall rains. This discussion is predicated on neutron meter measurements of Θ_v that are not based on on-site calibration. Therefore, the absolute values of Θ_v may be in error. Nevertheless, the differences in Θ_v at a given site should be reliable.

B. Tree heights. The pines on the Clay Site far outdistanced those on the Sandy Site, growing at a very nearly linear rate from early April to early August, (Fig. 12), at an average rate of 6 mm/day. In contrast, the pines on the Sandy Site grew at only half this rate over the same period, although their growth rate at first was high (5 mm/day from April to May). However, they did continue to grow until 24 November, a longer duration than for the pines at the Clay Site.

The growth rate of the Arizona cypress at the Clay Site accelerated significantly only during the period from 8 April to 24 May, attaining a very respectable rate of 6 mm/day and the[illegible] equalling the rate for the pines on the Clay and slightly exceeding that for the pines on the Sandy Site (5 mm/day). However, the growth rate steadily decreased from then on (Fig. [illegible]). The growth of these Arizona cypress trees cannot be compared with that of the same species at the Sandy Site because of age difference. The cypress trees at the Sandy Site were harves[illegible]d in 1981, and are being stump-cultured.

C. Rainfall. The total rainfall from the two Forrester rain gauges at Camp Verde was almost identical, even though the Clay Site (384.1 mm) was located 0.5 km away from the Sandy Site (383.8 mm). However, the rain gauge at the Camp Verde Ranger Station totaled 510 mm (Fig. 13). Since this official gauge was read daily, evaporative losses should have been minimal. Also, the location of the Ranger Station gauge presumably was close enough to our Forrester gauge at the Sandy Site (only 0.2 km apart) for them to be exposed to the same rainfall. Such a large discrepancy in readings is difficult to explain, especially when one considers that at both the Sandy and Clay Sites, oil was added to the rain gauge can after every reading to suppress evaporation between readings. Any inaccuracy in rainfall readings is reflected in the calculation of percentage runoff from a catchment and thereby in the estimate of the amount of water delivered to the trees.

IV. Harvest of Christmas Trees.

The number and quality of Christmas trees cut on 15 December 1982 is given in Table 1. Only 15 Quetta pines were harvestable at the Sandy Site (sand/wax), and they were rated Grade No. 3 by a panel of four judges (No. 1 = superior; No. 2 = good; No. 3 = average; and No. 4 = cull). Many trees have died at the Sandy Site. A survey taken in December 1982 showed the following numbers of living trees (from the original 25 trees per row): Row No. 1, 11; Row No. 2, [illegible]; Row No. 3, 17. Only one Quetta pine was harvestable last year from the Sandy Site. In summary, 37 pines at the Sandy Site have died in four years (49%), as compared with only three at the Clay Site (4[illegible]).

At the Clay Site (clay/salt) 48 Quetta pines were cut, having an average grade of 3. Only five Arizona cypress trees were considered harvestable out of the original 75 trees. The rest were judged either too small or culls.

The 48 Quetta pines were transported to Tempe, AZ, on the same day they were cut (strictly fresh) and donated to a charitable organization, which sold them competitively with other Christmas tree species. Each tree had a customer survey card for assessing quality and durability as well as general acceptance by the public. Returns so far have been uniformly favorable (about 25% of the cards having been returned).

SUMMARY AND CONCLUSIONS:

The main objective of the experiment has been fulfilled, viz., to grow Christmas trees rapidly from seedlings to near 2-m trees in three (Arizona cypress) or four years (Quetta pines) with runoff farming as the sole source of water, after the 3-month establishment period. Secondary objectives needing more research are the production of a higher-grade tree and stopping the steady loss of pines at the Sandy Site by sudden dying.

For 1982, Θ_v generally was higher in pine than Arizona cypress for a given catchment width. This may indicate a higher leaf area index for cypress or perhaps a higher transpiration rate. For the pines at the Sandy Site, Θ_v in treatment S-2 was significantly below that for S-1 and S-3 for the whole season. This was an anomalous response, since the amount of water delivered to S-2 should have been 50% more than for S-1. The RLWC data verified this relative standing, being significantly lower in S-2 than in S-1 or S-3. Finally, the height measurements also indicated treatment S-2 to be the one with the least growth. The treatment receiving the most water, S-3, definitely grew the tallest, followed by S-1 and then by S-2, a poor third place.

In the Arizona cypress plots at the Sandy Site, Θ_v was related to catchment width, both C-2 and C-3 being much better than C-1. However, these differences were not very well reflected in the values of RLWC. Tree height of C-2 was much greater than that of C-1 and C-3. In this instance, C-3 may have received supra-optimal amounts of water.

For Arizona cypress at the Clay Site, Θ_v was related to catchment width over the major part of the growing season, as was height toward the end of the season. However, values of RLWC did not differ much among treatments.

In brief, for the pines at the Sandy Site and the Arizona cypress at the Clay Site, the more water, the better growth. In contrast, for the pines at the Clay Site, the intermediate level of water produced the best growth. The reasons for these differences are being sought.

PERSONNEL: W. L. Ehrler, D. H. Fink, and J. M. R. Martinez

Table 1. Number and grade of harvestable Christmas trees at Camp Verde, AZ, in 1982 (four years after transplanting).

	No. of Harvestable Trees			
Site	Quetta Pines	Grade*	AZ Cypress	Grade*
Sand/Wax	15	3	(All 75 trees cut in 1981)	
Clay/Salt	48	3	5	4

*Range is from 1 (best) to 4 (cull).

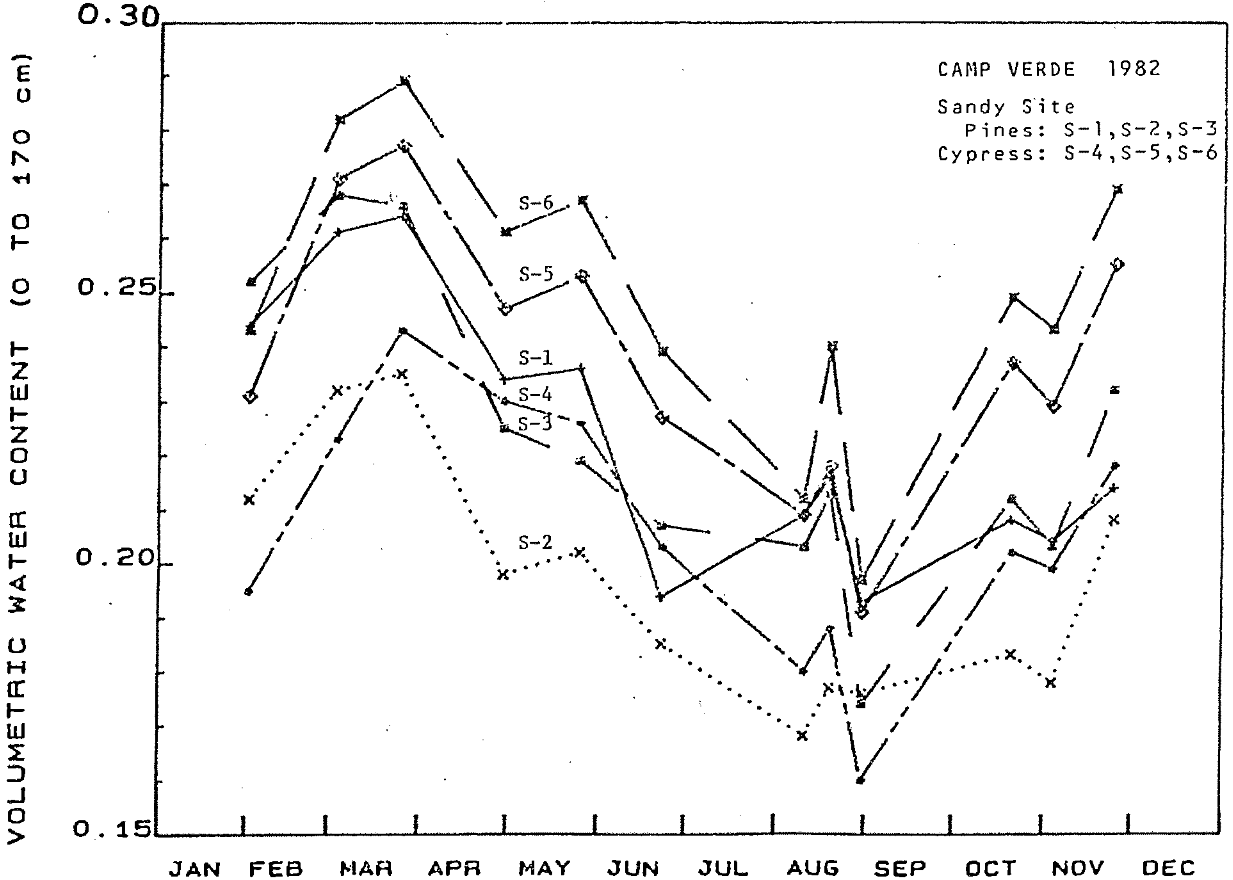

Fig. 1. The seasonal course of volumetric soil water content of six plots (Quetta pine and Arizona cypress) at the Sandy Site at Camp Verde in 1982.

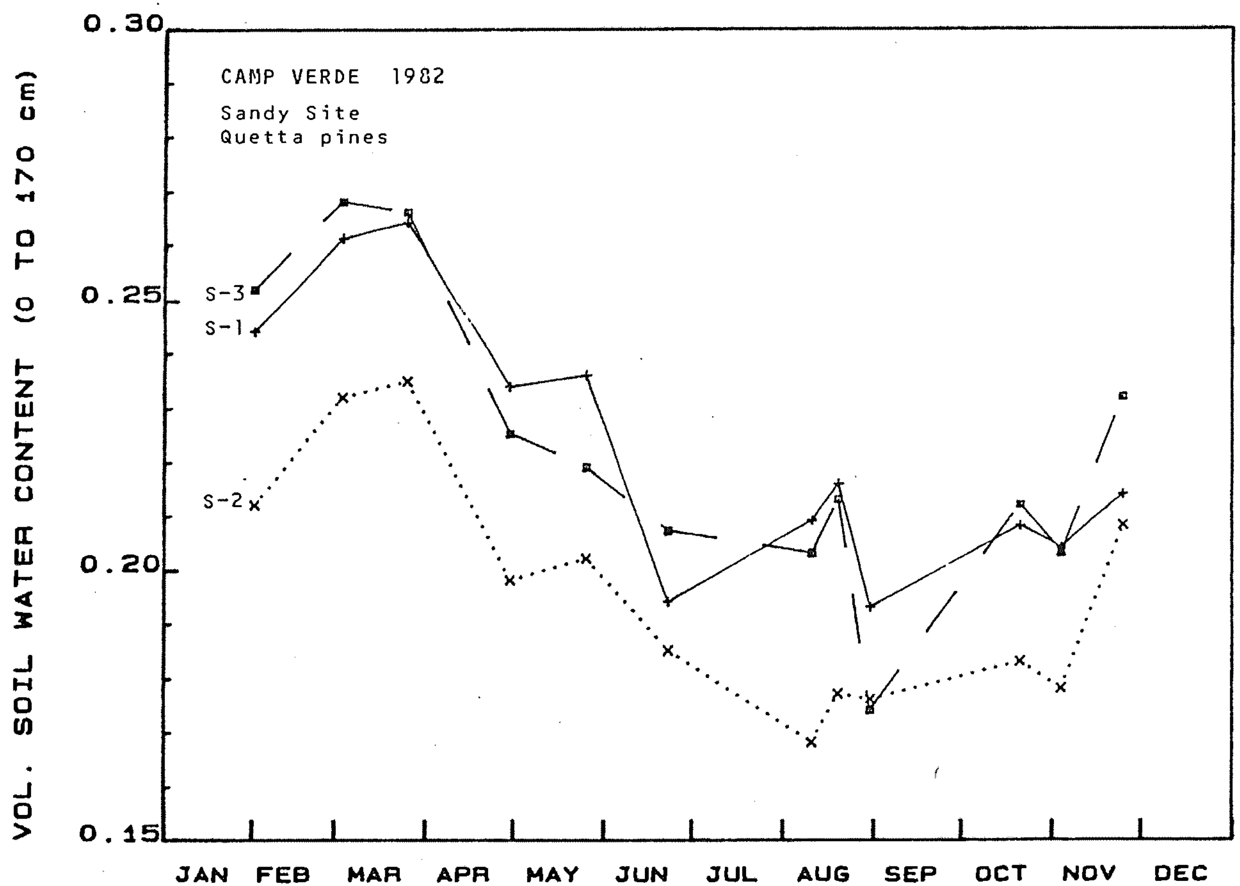

Fig. 2. The seasonal course of volumetric soil water content of three plots of Quetta pines with different catchment widths (S-3 > S-2 > S-1) at the Sandy Site at Camp Verde in 1982.

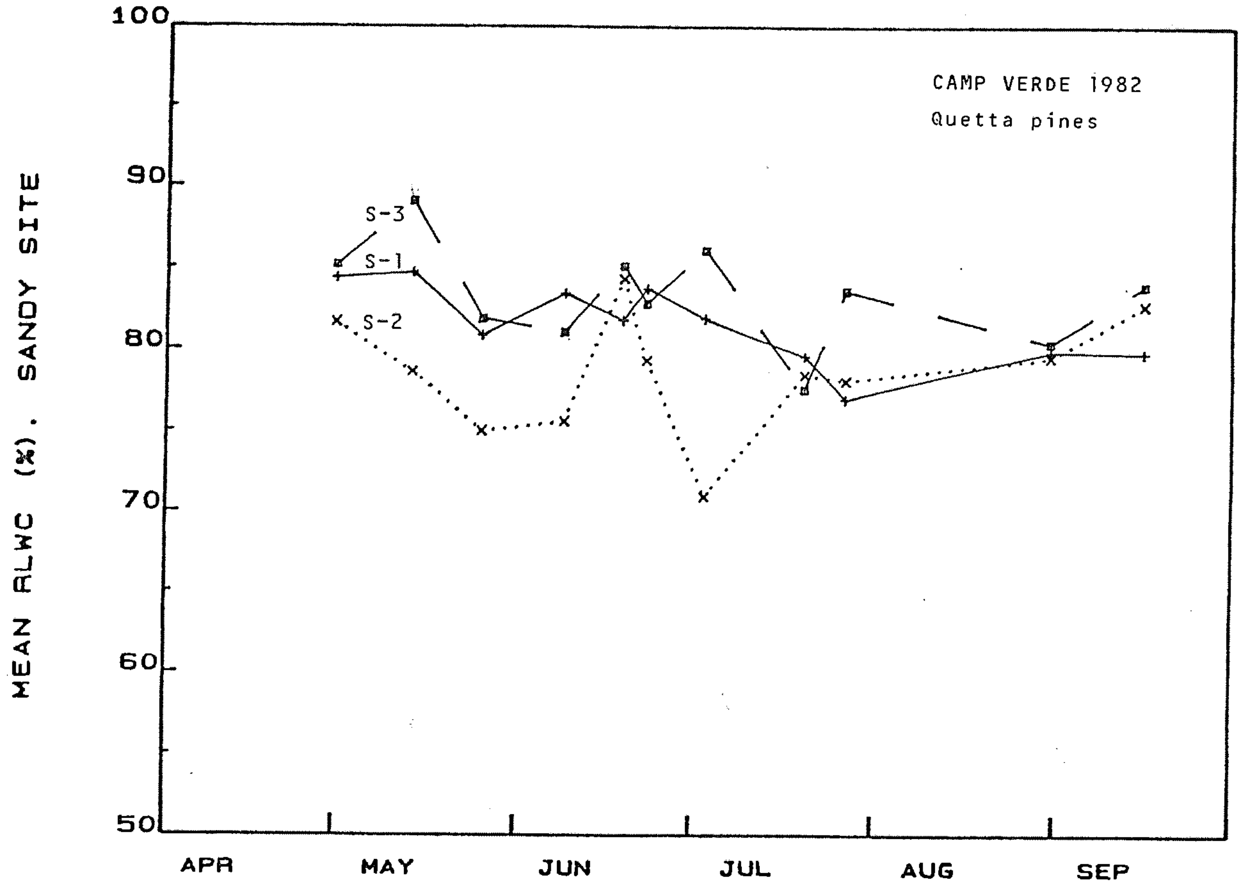

Fig. 3. The seasonal course of the relative leaf water content (RLWC) of three plots of Quetta pines at the Sandy Site at Camp Verde in 1982.

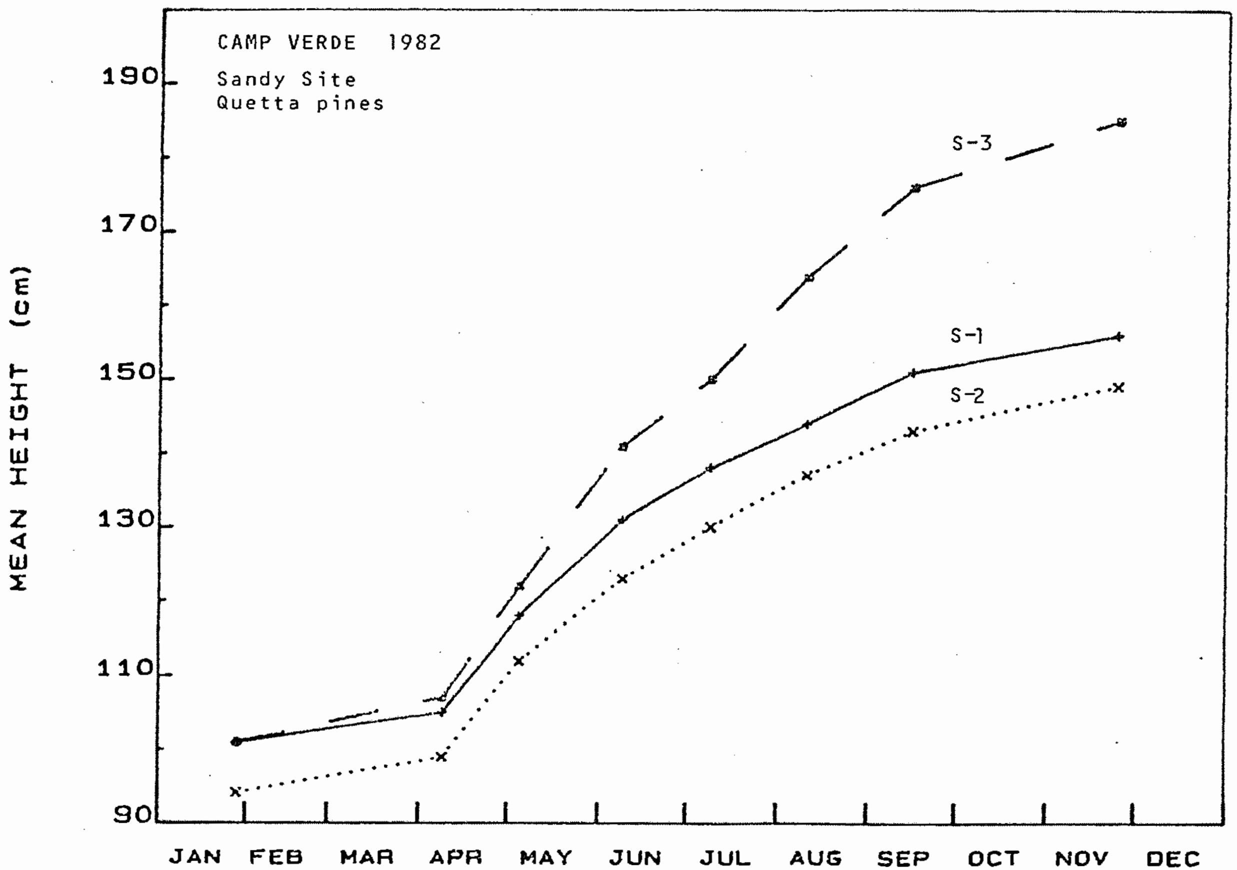

Fig. 4. The seasonal course of tree height (mean of four trees) of Quetta pines on three plots at the Sandy Site at Camp Verde in 1982.

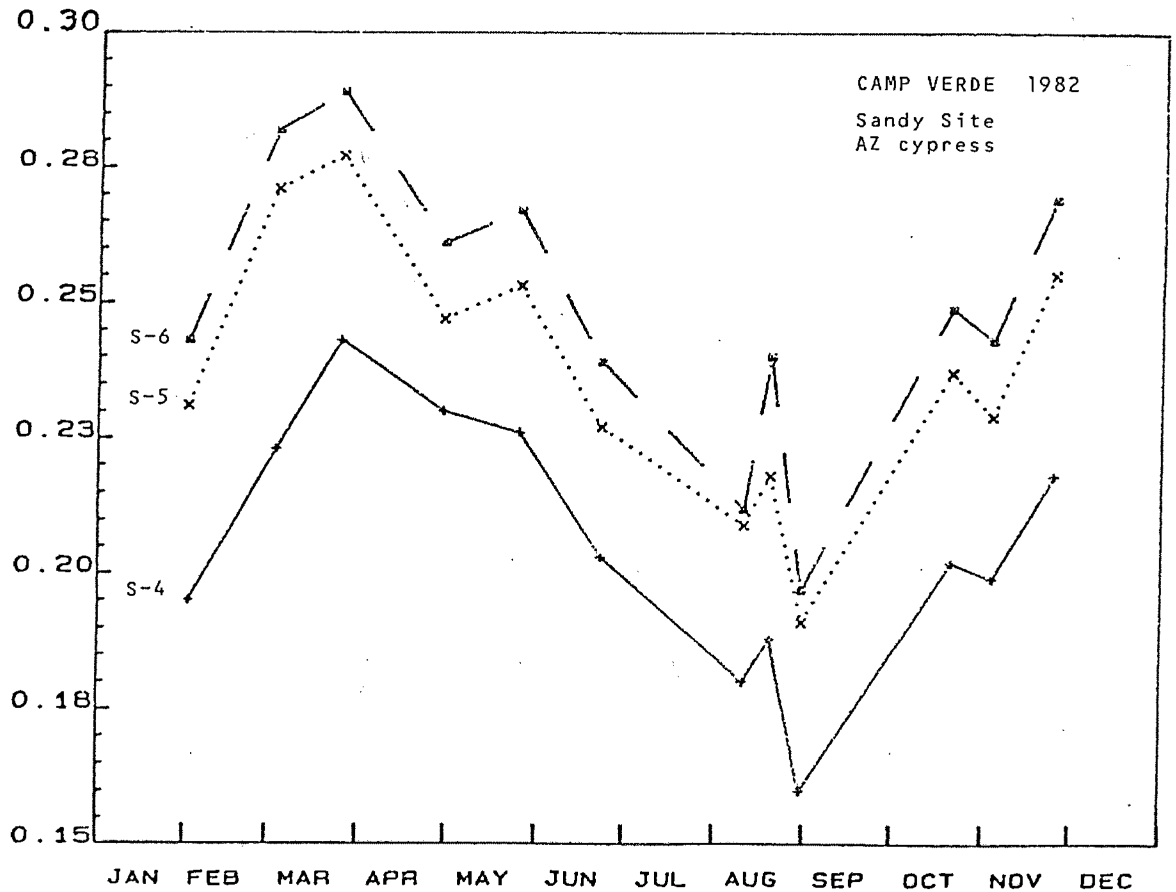

Fig. 5. The seasonal course of the volumetric soil water content of Arizona cypress trees at the Sandy Site at Camp Verde in 1982.

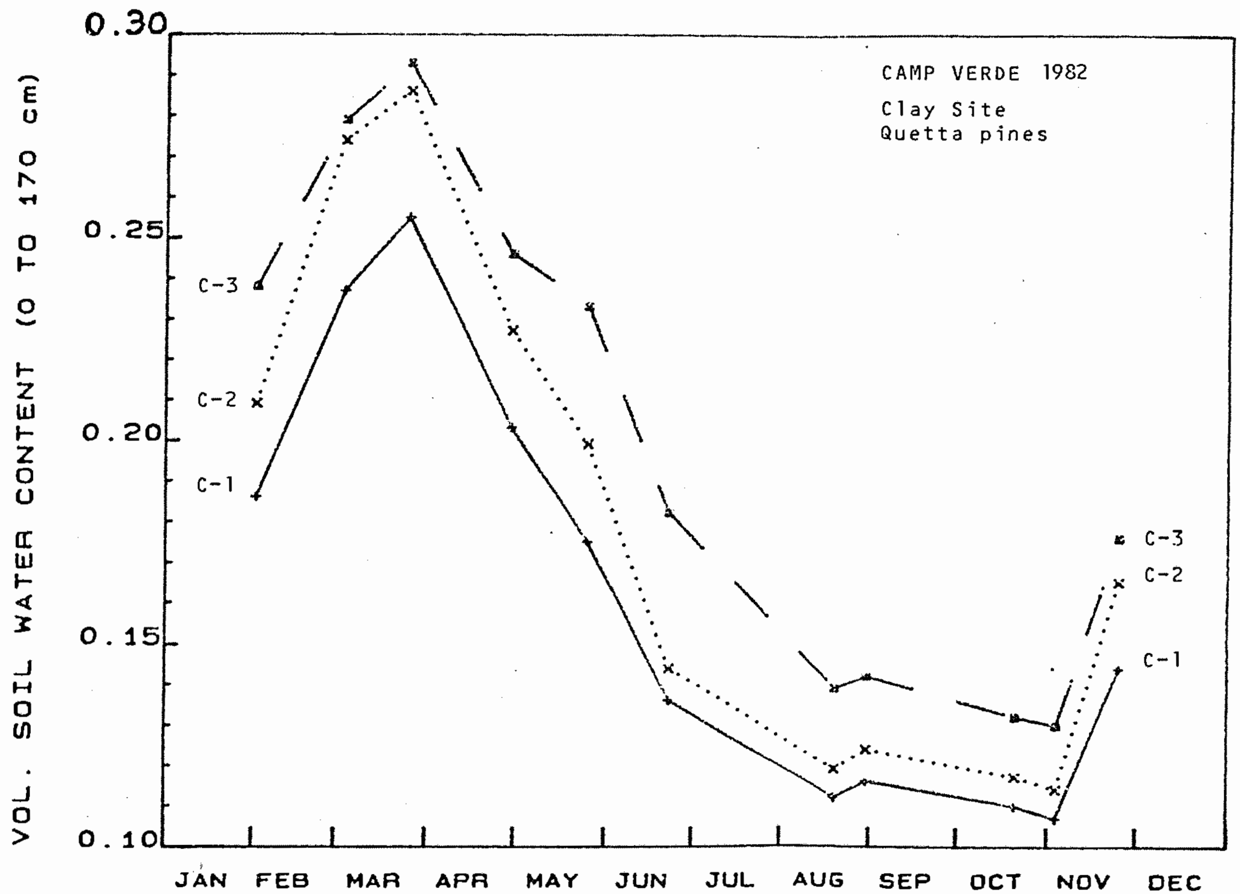

Fig. 6. The seasonal course of volumetric soil water content of three plots of Quetta pines at the Clay Site at Camp Verde in 1982.

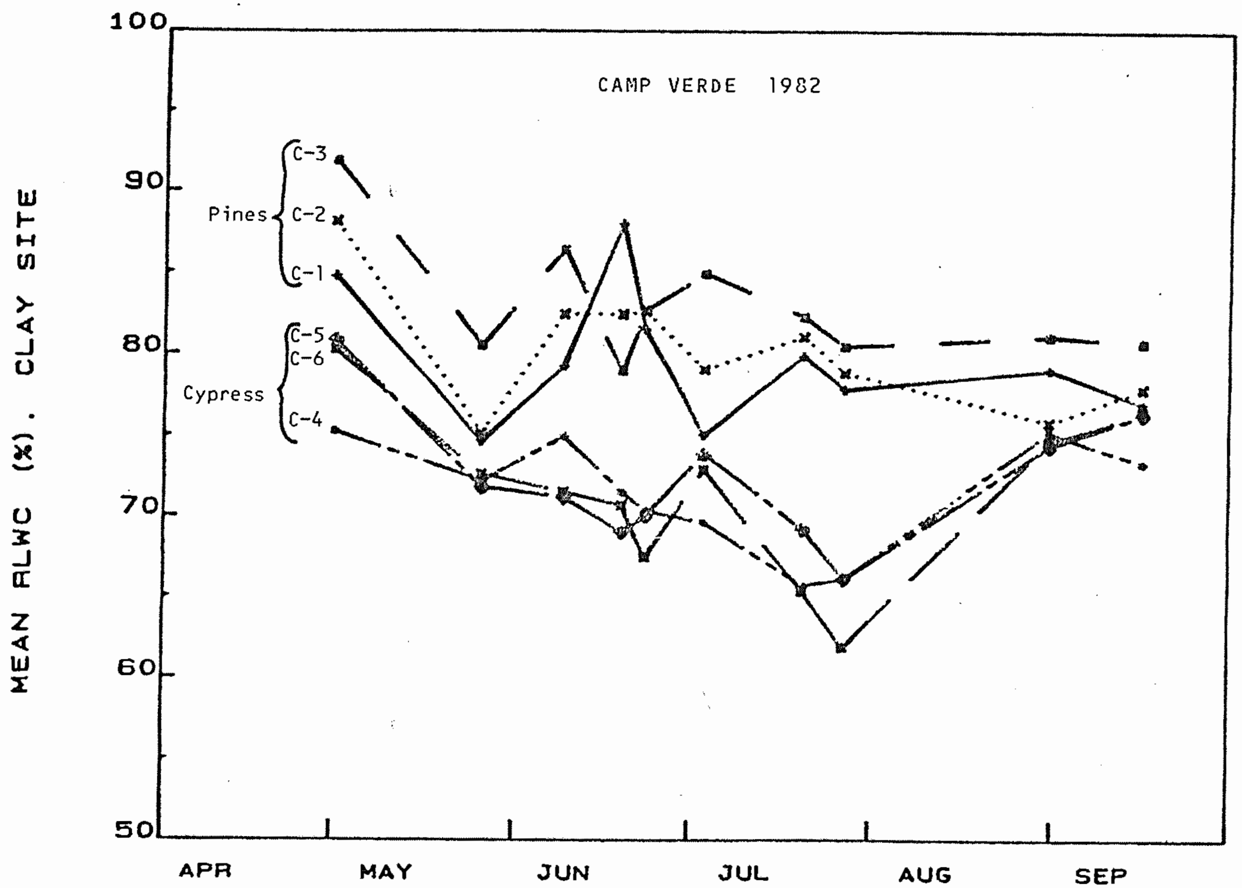

Fig. 7. The seasonal course of the relative leaf water content (RLWC, mean of four trees) in three plots each of Quetta pines and Arizona cypress at the Clay Site at Camp Verde in 1982.

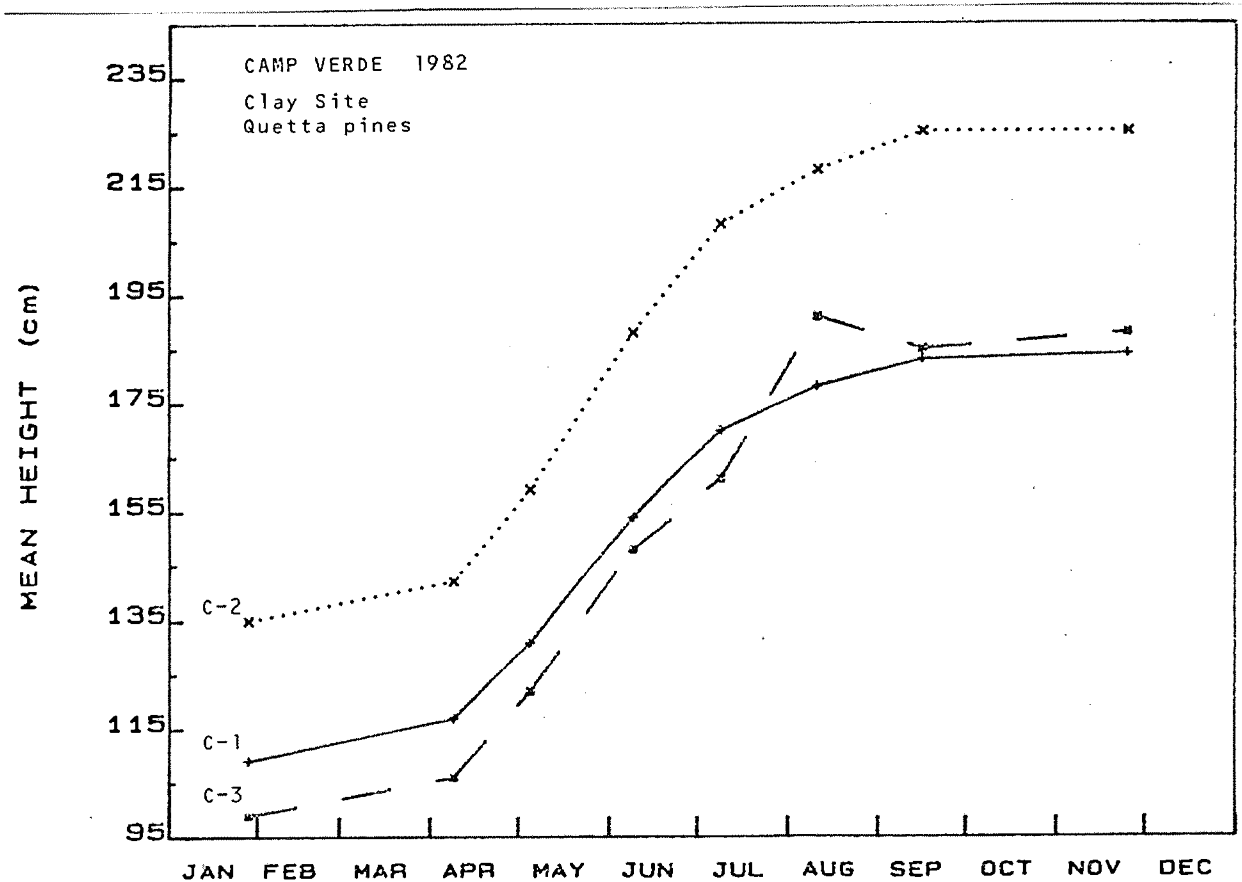

Fig. 8. The seasonal course of height (mean of 10 to 20 trees) of Quetta pines at the Clay Site at Camp Verde in 1982.

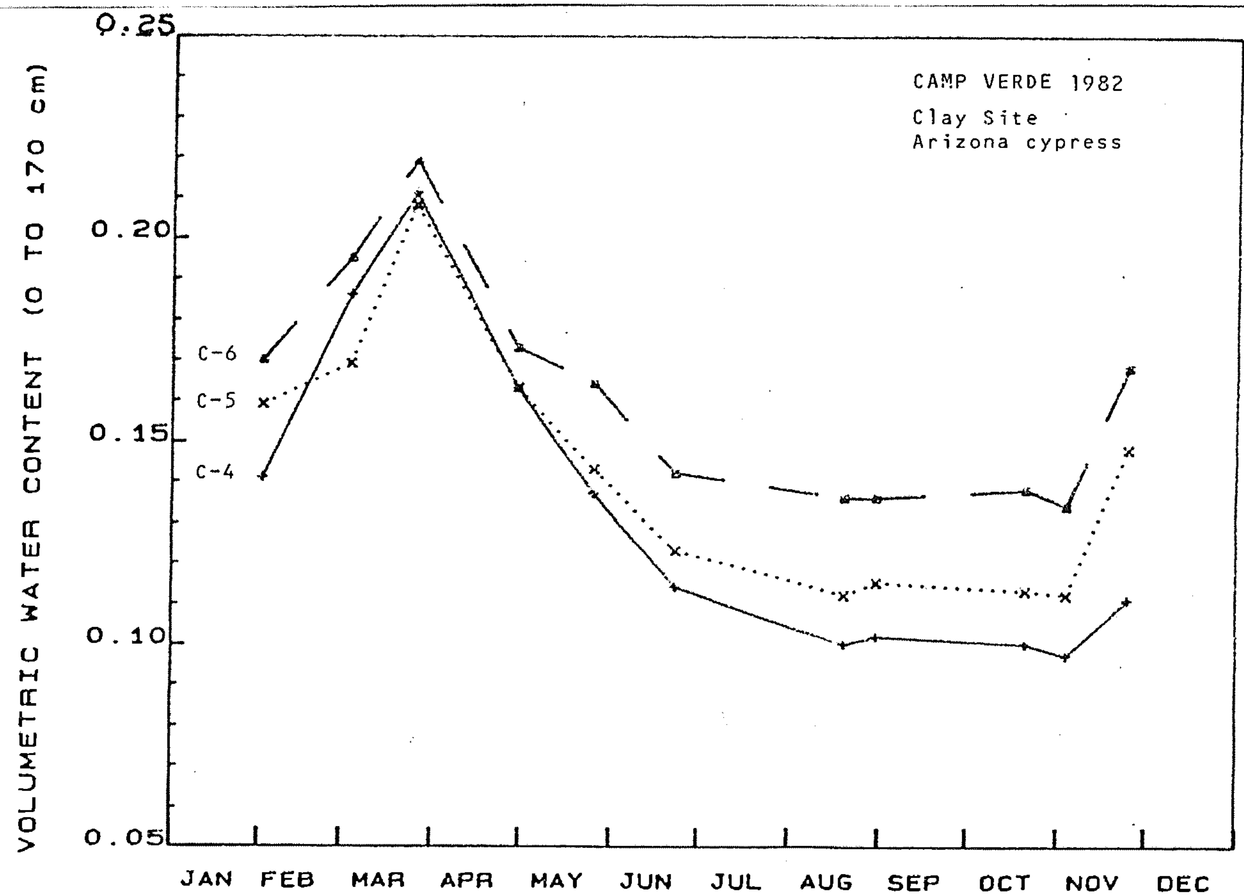

Fig. 9. The seasonal course of volumetric soil water content of three plots of Arizona cypress at the Clay Site at Camp Verde in 1982.

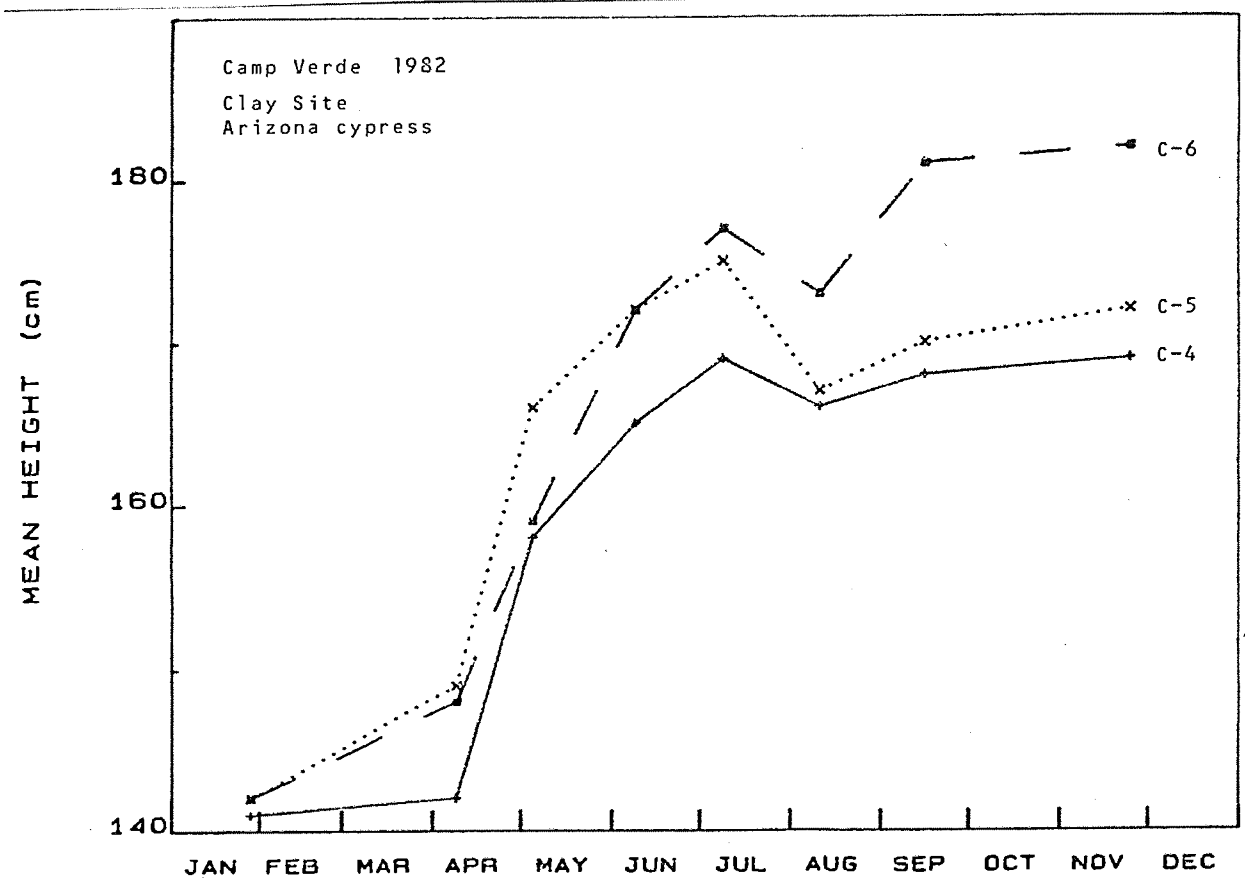

Fig. 10. The seasonal course of height (mean of 10 to 20 trees) of Arizona cypress at the Clay Site at Camp Verde in 1982.

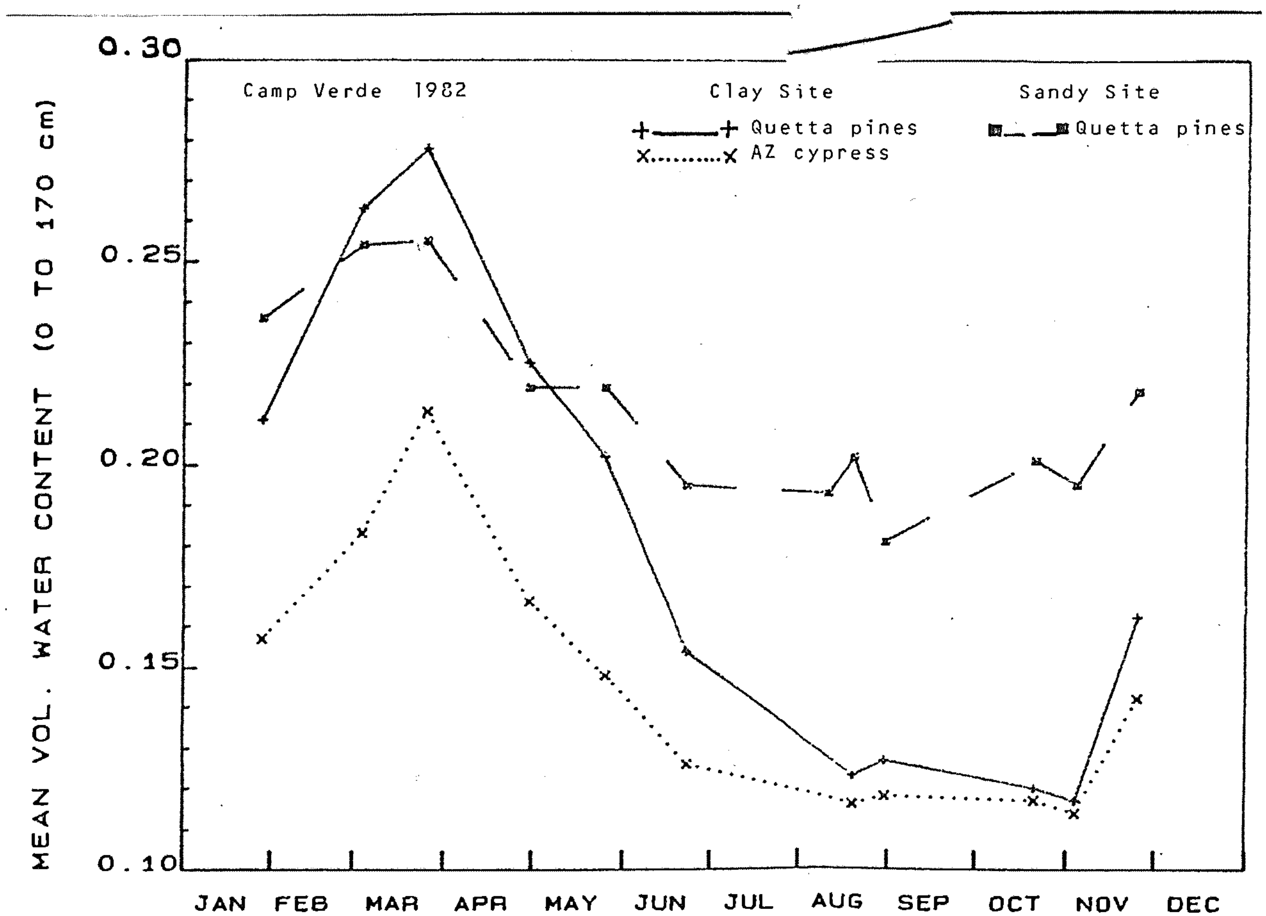

Fig. 11. A comparison of the seasonal course of volumetric soil water content for Quetta pines and AZ cypress (mean of three catchment widths) between the Sandy and the Clay Sites at Camp Verde in 1982.

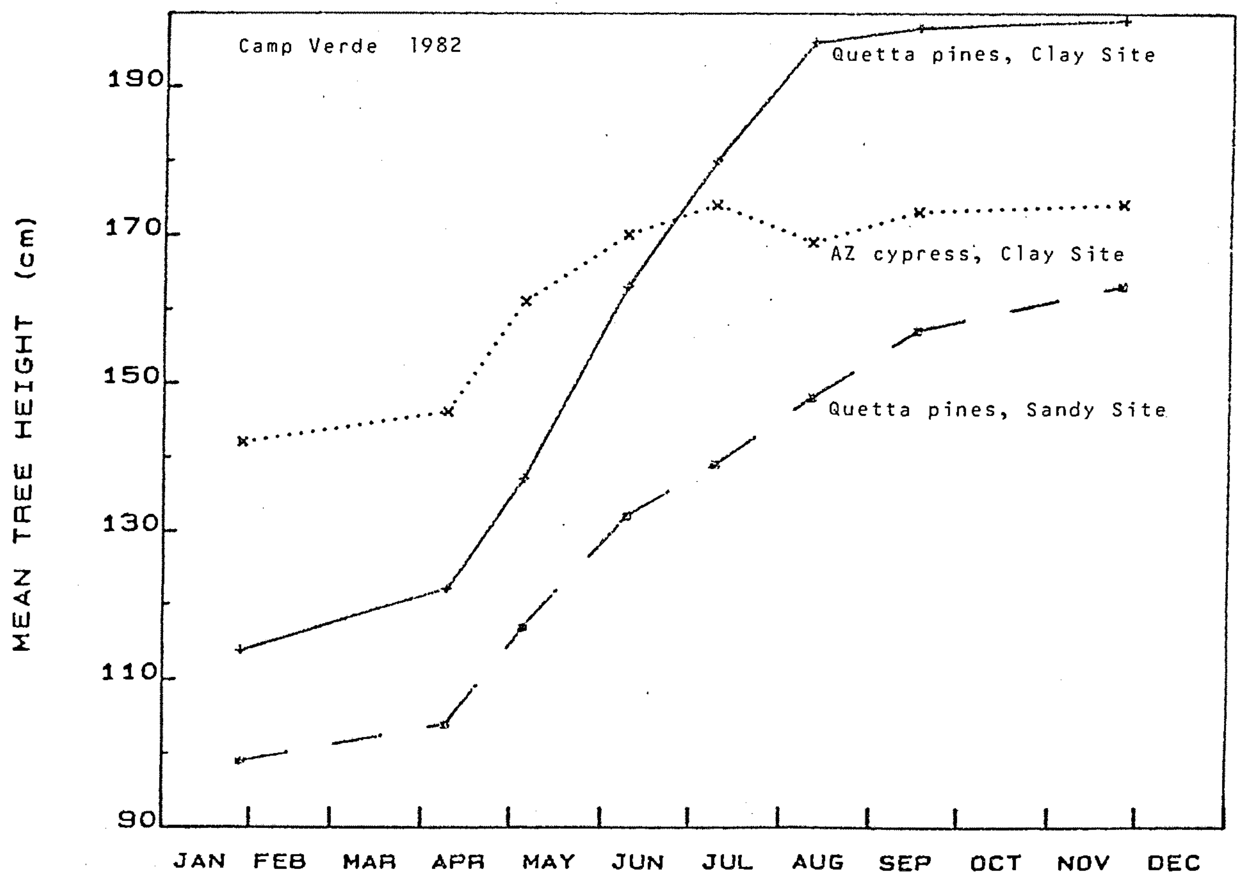

Fig. 12. A comparison of the seasonal course of tree height (mean of three catchment widths) among the Quetta pines and Arizona cypress at the Clay Site and the pines at the Sandy Site at Camp Verde in 1982.

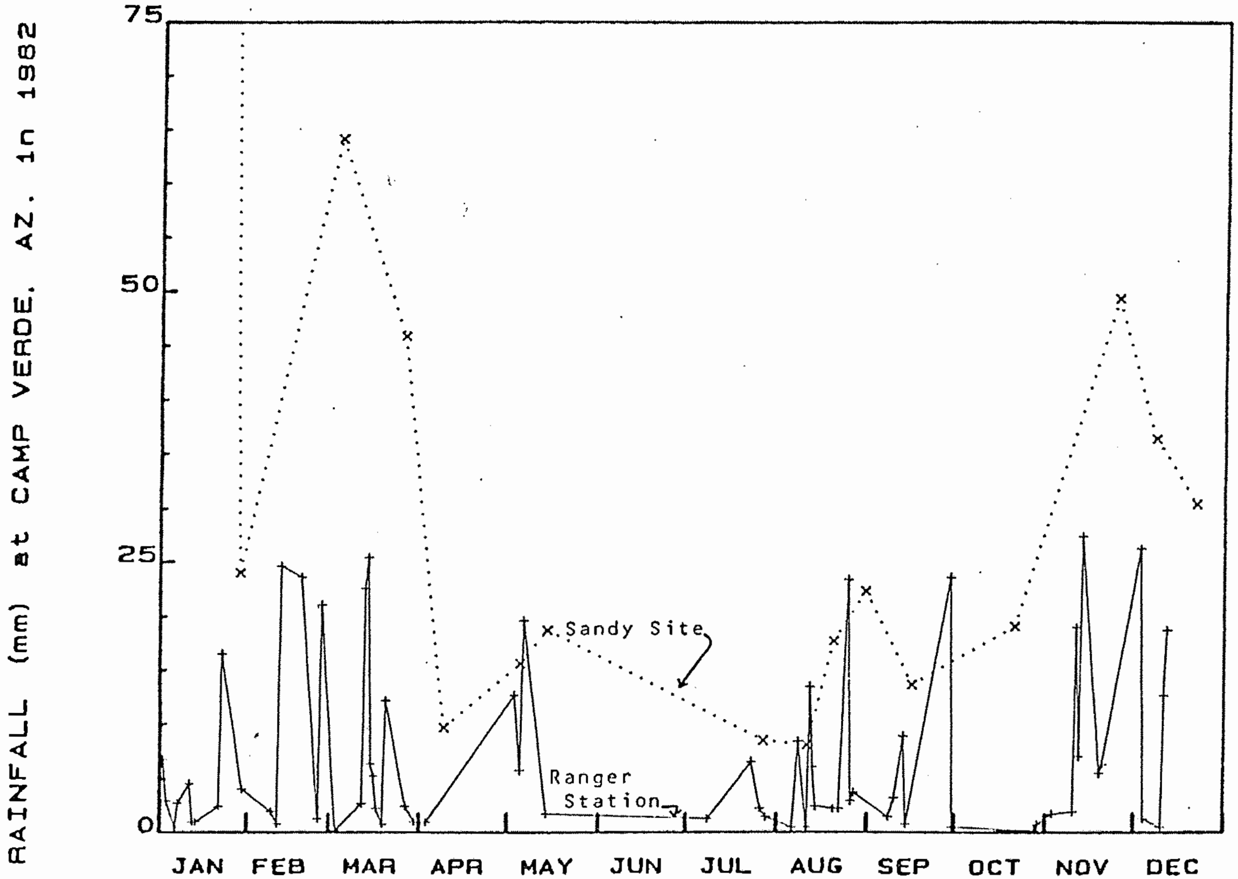

Fig. 13. A comparison of the 1982 rainfall measurements at Camp Verde between the Ranger Station and the Sandy Site Gauges.

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

NRP: 20760 CRIS WORK UNIT: 5510-20760-003

INTRODUCTION:

A total of 31 papers were pepared and/or published in 1982. Three papers dealt with ideas of using both reflected and emitted radiation as a means of evaluating various factors affecting plant growth and development. The potential of developing these remote sensing techniques for use in agriculture is discussed as are the problems which need to be solved before the techniques become operational. Plant temperature was used to assess stress for the purpose of estimating yield and scheduling irrigations in eight papers. One paper reviews the use of emitted thermal radiation from plants and another presents data from 26 plant species for non-water-stressed baselines. A third paper describes how humidity can be measured by infrared thermometry. The remaining papers deal with various aspects of evaluating stress in cotton. Estimating evapotranspiration (ET), is the subject of two manuscripts. One uses remotely sensed surface temperature to calculate an intantaneous value of ET while the other demonstrates how to estimate daily ET from a once-a-day measurement. Atmospheric effects on surface temperature and reflected radiation are described in nine papers. They vary from defining a surface air temperature response function for the earth's atmosphere to a description of diurnal patterns of wheat spectral reflectances to an evaluation of longwave radiation calculation models. Nine manuscripts are concerned with carbon dioxide, climate and agriculture. The role of the water vapor feedback mechanism is questioned in light of some recently published global temperature data. An analysis of published information shows that crop yields may be increased by 1/3 from a doubling of atmospheric CO_2, while water use efficiency may double. A short description of the ANZA 82 wheat experiment is given.

REMOTE SENSING IN AGRICULTURE:

1. Jackson, R. D. "Plant health: A view from above". Chapter in book Challenging Problems in Plant Health. American Phytopathological Society. (In press).

A plant health monitoring system that uses advanced sensors mounted on a radically different satellite is proposed. Farm operators could readily process data and make management decisions based on information contained in images of fields shown on a TV monitor. Relationships between various soil, plant, disease, and insect factors and remotely sensed parameters would be part of the computer software. At the press of a key an image highlighting disease incidence in a particular field would appear. The fraction of the field affected would be automatically calculated and the category of disease identified. Pressing another key would examine the area for water stress, etc. Research challenges that must be met before such a monitoring system can be developed are discussed.

2. Jackson, R. D. Assessing moisture stress in wheat with hand-held radiometers. Society Photo-optical Instrumentation Engineers. (In press).

Hand-held radiometers that measure reflected solar and emitted thermal radiation are useful for evaluating agronomic parameters. An example application is presented which shows that thermal measurements can detect water stress before visual signs appear. Reflected solar measurements can be used to document the history of stress, and are useful for calibrating the thermal parameter at various degrees of stress. Some special requirements of instruments that are to be used in field experiments are discussed.

3. Wiegand, C. L., Nixon, P. R., and Jackson, R. D. Drought detection and quantification by reflectance and thermal responses. Agric. Water Mgt. (In press).

Drought can be detected by its effect on plant canopy development as indicated by measurements of biomass production, leaf area index (LAI), and ground cover in the reflective wavelengths (0.4 to 2.5 µm) and by canopy minus air temperature in the thermal infrared (8 to 14 µm) wavelengths. Both measures are quantitative, but quantification in terms of drought's economic impact requires that relationships between canopy "appearance" as revealed by the measurements and effect on salable plant parts must be established. The measurements themselves are becoming routine and their quantification in terms of drought's economic impact on grain sorghum and wheat grain yields have been demonstrated, but are not yet routine. Seven considerations in a system for drought quantification are discussed, and results of semi-operational applications to drought assessment that incorporate most of the seven considerations are described. Future drought assessment systems will likely combine physiologically based crop growth and yield models with soil characteristics, weather data, and Earth satellite spectral scanner observations.

CROP WATER STRESS INDEX:

4. Idso, S. B. Yield prediction -- development of a concept using remote sensing. In: Problems in Crop Physiology, Vol. 2 (U. S. Gupta, ed.), Oxford and IBH Pub. Co., New Delhi. (In press).

A shared objective of all people engaged in agricultural pursuits is to raise the most produce with the least expenditure of funds and effort. That is to say, the common goals of high productivity and maximum operating efficiency are ideals to which farmers always aspire, but of which they often fall short. Hence, agricultural research continually probes for new ways to reduce the gap between idealism and the harsh realities of the unpredictable world within which the agricultural enterprise is conducted.

One of the primary areas of concern in this regard is that of reducing the severity and longevity of plant water stress induced by insufficiency of soil moisture, or to optimally schedule irrigations. The key to success in this operation is obviously the timely and accurate assessment of plant water status; and there is no way in which this can be done over large areas without employing some type of remote sensing technique. Thus, this review focuses on recent developments in this field which show promise of becoming practical operational realities in the very near future.

5. Idso, S. B. Humidity measurement by infrared thermometry. Remote Sens. Environ. 12:87-91.

A promising new approach to the remote sensing of plant water stress involves the evaluation of an index that is dependent upon air temperature and vapor pressure, in addition to the basic foliage temperature. The air temperature measurement is already being made by an appropriate sensor incorporated into some infrared thermometers; but the vapor pressure measurement has required a second instrument. This paper describes a technique for obtaining the vapor pressure measurement by viewing the cloudless sky directly overhead with the infrared thermometer itself, thus doing away with the need for a second instrument in the remote field assessment of plant water stress by infrared thermometry.

6. Idso, S. B. Non-water-stressed baselines: A key to measuring and interpreting plant water stress. Agric. Meteorol. 27:59-70.

A plant water stress index has recently been developed which employs a radiometric measurement of foliage temperature and a psychometric measurement of the vapor pressure deficit of the air. To utilize the index, it is necessary to know the relationship that exists between foliage-air temperature differential and air vapor pressure deficit for the plant in question when it is well watered and transpiring at the potential rate. This information is provided for 26 different species for clear sky conditions in the format of non-water-stressed baselines. For six of these plants, including one aquatic species, such information is also included for cloudy or shaded conditions; and two grain crops have results presented for both pre-heading and post-heading stages.

7. Idso, S. B., Reginato, R. J., and Radin, J. W. Leaf diffusion resistance and photosynthesis in cotton as related to a foliage air temperature based plant water stress index. Agric. Meteorol. 27:27-34.

Leaf diffusion resistance and net photosythesis measurements were made over several daylight periods throughout the summer of 1981 on four plots of cotton grown under two different irrigation regimes at Phoenix, Arizona. Both of these physiological measurements correlated highly with a recently developed plant water stress index that essentially normalizes the stress-degree-day parameter for environmental variability.

8. Idso, S. B., Reginato, R. J., and Farah, S. M. Soil- and atmosphere-induced plant water stress in cotton as inferred from foliage temperatures. Water Resources Res. 18:1143-1148.

Foliage temperatures of cotton obtained by means of infrared thermometry, along with air wet and dry bulb temperature measurements, were used to investigate certain relationships existing between the water contents of soil and air and the ability of the crop to maintain transpiration at the potential rate. It was found that as soil water content is progressively depleted following an irrigation, departure from potential transpiration begins to occur at smaller and smaller values of air vapor pressure deficit in a regularly predictable fashion. It was also demonstrated that the plant water potential of cotton transpiring at the potential rate is a function of the air vapor pressure deficit and that the difference between this base value and the tension that develops under nonpotential conditions is a unique function of a newly developed plant water stress index. Finally, an example of the application of this foliage temperature-based index to evaluating the effects of an irrigation event is presented.

9. Pinter, P. J., Jr., and Reginato, R. J. A thermal infrared technique for monitoring cotton water stress and scheduling irrigations. Trans. ASAE. 25(6):1651-1655.

Research on short staple cotton at Phoenix has demonstrated that the crop water stress index (CWSI) calculated from radiant canopy temperatures and air vapor pressure deficits (VPD) is well correlated with the leaf water potential of cotton leaves during the middle portion of the growing season. When the crop age and the influence of VPD on leaf water status are also taken into account, the CWSI can be used to predict leaf water potential early in the season when plants are relatively small and also later when foliage is beginning to senesce.

The relationship between predicted and observed leaf water potential is shown in Figure A. Calculations were based on the equation:

$$\Psi_1 = -0.274 - 0.905\ (CWSI) - 0.010\ (AGE) - 0.19\ (VPD)$$

$$n = 1.47 \quad r2 = 0.76 \quad se = 0.27\ MPa$$

where Ψ_1 is the predicted midday leaf water potential (MPa), CWSI is based on 1330 radiant leaf temperatures, the age of the crop is in days since planting and VPD is in KPa. This relationship permits rapid daily monitoring of plant water status without resorting to tedious physiological measurements.

10. Pinter, P. J., Jr., Fry, K. E., Guinn, G., and Mauney, J. R. Infrared thermometry: A remote sensing technique for predicting yield in water-stressed cotton. Agric. Water Management. (In press).

Cooperative research between personnel at the U. S. Water Conservation Laboratory and the Cotton Research Center, Phoenix, AZ has demonstrated the utility of infrared thermometry in predicting the yield of an indeterminate crop such as cotton. The average mid-day CWSI values of 12 cotton plots which received different early season irrigation treatments (represented by the triangular symobls of Figure B) were inversely correlated with final seed cotton yield in 1980. When 1981 data from Westlake Farms, CA (circles in Figure B) were superimposed on these data, they fell along with same trend line even though seed cotton yields exceeded those observed at Phoenix by as much as 1500 kg/ha.

11. Reginato, R. J. Field quantification of crop water stress. Trans. ASAE. (In press).

Canopy temperature is used to quantify crop stress by use of a crop water stress index (CWSI). The index can be developed empirically and theoretically and advantages of each approach are described. Relationships between the CWSI and traditional plant stress parameters such as leaf water potential and stomatal conductance are presented for cotton. The daily change in CWSI for cotton shows its dynamic response to changing atmospheric demand and soil moisture conditions. The value of the CWSI is shown in terms of scheduling irrigations and predicting lint cotton yield.

EVAPOTRANSPIRATION:

12. Hatfield, J. L., Perrier, A., and Jackson, R. D. Estimation of evapotranspiration at one time-of-day using remotely sensed surface temperatures. Agric. Water Mgt. (In press).

The estimation of evapotranspiration on a regional scale may be possible using remotely sensed inputs to surface energy balance models. Energy balance considerations lead to a relation that includes net radiation, surface and air temperatures, a stomatal and an aerodynamic resistance, as inputs. The latter resistance term was examined as to its behavior under both stable and unstable temperature conditions, several surface roughness conditions, and at various windspeeds. The models show that the evapotranspiration is higher than net radiation when the surface is cooler than the air and lower when the surface is warmer than the air. The aerodynamic resistance changes due to surface-air temperature differences play a substantial role in determining evapotranspiration. To test the models, evapotranspiration was calculated using remotely sensed temperatures, with the remaining inputs conventionally assessed. The calculations were made for a one-time-of-day period near midday, as would be required for a remote sensing technique, and were compared to lysimetrically determined evapotranspiration. The measured data were obtained at several locations in the Western United States, and were for a variety of crops. The good agreement between calculated and measured values indicates that the goal of developing techniques that produce accurate evapotranspiration estimates over large areas is attainable.

13. Jackson, R. D., Hatfield, J. L., Reginato, R. J., Idso, S. B., and Pinter, P. J., Jr. Estimation of daily evapotranspiration from one time of day measurement. Agric. Water Mgt. (In press).

The estimation of evapotranspiration over large areas requires remote sensing inputs. Since these are usually one time of day measurements it is necessary to develop a coefficient to convert these essentially instantaneous measurements to daily totals. A coefficient was derived from theoretical considerations that can be applied from 60 degrees south to 60 degrees north latitude. Inputs other than latitude are day of year and time of day. Estimated daily totals from one time of day measurements agreed very well with measured daily totals from five locations in the U.S. and for four different crops.

ATMOSPHERIC EFFECTS ON RADIATION:

14. Hatfield, J. L., Reginato, R. J., and Idso, S. B. Comparison of longwave radiation calculation models over the United States. Water Resources Res. (In press).

Several models to estimate longwave radiation from the atmosphere were evaluated at 15 locations in the United States over a range in latitude from 26°13'N to 47°46'N and over an elevation range from -30 m to 3342 m. Screen level air temperature and/or water vapor pressure were the only data required to drive the seven models. Three of the models adequately estimated longwave radiation with an error of less than 5% for most agricultural locations in the United States.

15. Idso, S. B. A surface air temperature response function for earth's atmosphere. Boundary Layer Meteorol. 22:227-232.

A property of Earth's atmosphere called the surface air temperature response function is defined to be the change in surface air temperature that results from a change in radiant energy absorbed at the planet's surface. It is experimentally evaluated by three independent techniques to yield a value over land of 0.172K $(Wm^{-2})^{-1}$, while one of these techniques yields a value about half that great for stations on the extreme west coast of the United States. Computing an appropriate global upper limit from these two results yields a value of 0.113K $(Wm^{-2})^{-1}$, which compares well with a fourth technique that yields a mean global value of 0.097K $(Wm^{-2})^{-1}$. The results imply an unexpected time-scale invariant response function.

16. Idso, S. B. On calculating thermal radiation from cloudless skies. Arch. Met. Geophys. Biokl. (In press).

Several recent empirical findings and theoretical developments related to the estimation of clear-sky atmospheric thermal radiation are discussed. It is demonstrated that the radiative behavior of water vapor at air temperatures above freezing has been parameterized as well as can or need be done, but that there may be room for some improvement at air temperatures below freezing. It is additionally shown that any procedure designed to accurately calculate atmospheric thermal radiation must be able to handle effects of airborne dust variability of both a temporal and spatial nature.

17. Idso, S. B. Long-term stabilization of earth's surface air temperature by a negative feedback mechanism. Arch. Met. Geophys. Biokl., Ser. B. (In press).

A potential negative feedback relationship between atmospheric relative humidity and surface air temperature is described. Together with a recently proposed negative feedback mechanism involving atmospheric CO_2, the phenomenon may be sufficient to prevent the global ice catastrophies which are a common prediction of many climate models following initial development of ice age conditions, and could well be of importance for the problem of the cool sun in Earth's early history.

18. Jackson, R. D., Slater, P. N., and Pinter, P. J., Jr. Discrimination of growth and water stress in wheat by various vegetation indices through a clear and a turbid atmosphere. Remote Sens. Environ. (In press).

Hand-held radiometers were used to measure light reflected from drought-stressed and well-watered wheat over an entire growing season. Using a model for atmospheric scattering, the ground measured reflectances were transformed to simulate satellite data for two different atmospheric conditions. Several commonly used vegetation indices were examined for their ability to discriminate vegetation and to detect stress, under a clear and a turbid atmosphere. The various vegetation indices differed in their ability to discriminate agronomic parameters at different growth stages and for different atmospheric conditions. The results provide a basis for selecting the most useful index for a particular set of conditions.

19. Jackson, R. D., Slater, P. N., and Pinter, P. J., Jr. Adjusting the tasseled cap brightness and greenness factors for atmospheric path radiance and absorption on a pixel by pixel basis. Intern. J. Remote Sens. (In press).

Satellite data is used to measure changes in ground surface conditions of soils and vegetation. The atmosphere affects the measurement because some solar radiation is scattered by aerosols and reaches the satellite sensor without first striking the ground. Some radiation is also absorbed by water vapor. Satellite data was simulated using an atmospheric radiative transfer model and ground measured reflectances. A method was developed to adjust for atmospheric effects on a pixel by pixel basis, thus accounting for spatial variability of aerosols. If the procedure withstands critical tests with actual satellite data, than vegetation could be measured without the complicating effects of the atmosphere.

20. Kimball, B. A., Idso, S. B., and Aase, J. K. A model of thermal radiation from partly cloudy and overcast skies. Water Resources Res. 18:931-935.

A mathematical model for predicting thermal radiation from partly cloudy and overcast skies was developed. The model uses previous clear sky equations for predicting full-spectrum sky emittance and 8-14 µm atmospheric window transmittance and then assumes that the cloud contribution to sky thermal radiation must be transmitted to the earth's surface through the atmospheric window. Unlike previous 'cloud correction,' th cloud contribution is computed from surface vapor pressure and temperature, cloud amount, and elevation data, as recorded by the National Weather Service observers. The average predicted increase due to 100% cloud cover was 18% for Phoenix in 1978 with a theoretical upper limit about 40%. Comparisons were made between model predictions and measured values of sky radiation for a wide range of weather conditions. The agreement was excellent with an overall coefficient of determination fo fit to a 1:1 line of 0.941 on an hourly basis and 0.960 on a daily total basis.

21. Pinter, P. J., Jr., Jackson, R. D., Idso, S. B., and Reginato, R. J. Diurnal patterns of wheat spectral reflectances. IEEE Trans. on Geosci. and Remote Sens. (In press).

A handheld radiometer with bandpass characteristics similar to the MSS radiometer on LANDSAT satellites was used to document the effect of changing sun angles on the reflectance properties of Produra wheat canopies in various phenological stages and at different levels of green leaf area. Results revealed substantial changes in each individual waveband as well as several vegetation indices derived from them. These diurnal changes were attributed to differences in canopy architecture, percent cover and the vertical distribution of green leaves within the canopy. Further analysis showed that substantial errors could be introduced int the estimate of green leaf area index from reflectance measurements if the changing angles of illumination are not properly accounted for.

22. Slater, P. N., and Jackson, R. D. Atmospheric effects on radiatio reflected from soil and vegetation as measured by orbital sensors using various scanning directions. Appl. Optics. 21:3923-3931.

Ground-measured spectral reflectance data for Avondale loam and drought stressed and unstressed wheat were converted into digital counts for spectral bands 5 and 7 of the Landsat Multispectral Scanner System (MSS). For dry loam, the differences between ratios of MSS bands 7-5 as determined from space and from ground level measurements were 2.3% for clear and 5.6% for turbid atmospheric conditions. By contrast, for wet loam the differences were 10.4 and 29.5%. We found that atmospheric conditions may cause a delay of from 3 to 7 days in the discrimination between drought stressed and unstressed wheat. For oblique angle observations the atmospheric modification of ground-measured reflectances increased with angle at a greater rate in the 0/180° azimuth. Implications of this result are discussed for oblique angle Systeme Probatoire d'Observation de la Terre (SPOT), Mapsat, future multispectral linear array system imagery, and wide-angle imagery collected from scanners in high-altitude aircraft.

CARBON DIOXIDE, CLIMATE AND AGRICULTURE:

23. Idso, S. B. An empirical evaluation of earth's surface air temperature response to an increase in atmospheric carbon dioxide

concentration. In: AIP Conf. Proc. No. 82: Interpretation of Climate and Photochemical Models, Ozone and Temperature Measurements," R. A. Reck and J. R. Hummel, eds., Amer. Inst. Physics, New York, pp. 119-134.

This paper reviews a large body of experimental work carried out by the author over the past dozen years, which comes to bear upon the question of climatic consequences of increasing CO_2 concentrations. It is contended that these studies of the real world indicate that the magnitude of Earth's surface air temperature response to a CO_2-induced radiational perturbation has been overestimated by most of the theoretical numerical models of the atmosphere by a full order of magnitude, and that there will be no significant climatic change elicited by future realistic increases in atmospheric CO_2.

24. Idso, S. B. Temperature limitation by evaporation in hot climates and the greenhouse effects of water vapor and carbon dioxide. Agric. Meteorol. 27:105-109.

Simple energy balance considerations and historic temperature data indicate that there are rather sharply defined upper limits to which air temperature may rise above the tropical oceans and and expansive well-watered terrestrial surfaces. Measurements of full-spectrum and 10.5-12.5 µm thermal radiation from the cloudless atmosphere indicate that an analogous temperature limit also exists for other land areas of the globe, thereby greatly restricting the magnitude of climatic change that may occur as a result of the greenhouse effects of increasing concentrations of atmospheric water vapor and carbon dioxide.

25. Idso, S. B. Carbon dioxide and global temperature: What the data show. Jour. Environ. Quality. (In press).

Data from a number of sources are presented to indicate that (1) there was a gradual increase in global atmospheric CO_2 concentration from about 1860 to 1945, (2) there has been a much more rapid rate of increase in atmospheric CO_2 concentration from 1945 to the present, (3) the most recent trend of global surface air temperature during this period of rapid CO_2 increase has been downwards, in contradiction to the predictions of the most sophisticated general circulational models of the atmosphere in use today, (4) this downward trend in surface air temperature has been most pronounced in northern latitudes, also in contrast to the model predictions, and (5) the downward temperature trend has been greater in summer than in winter, again in contradiction to the models. It is thus concluded that the theoretical numerical models of the atmosphere are grossly in error in their predictions of future CO_2 effects on world climate, as is also suggested by several recent empirical studies. Consequently, since global population continues to climb and require more and more food, and since elevated CO_2 concentrations have been documented to enhance crop productivity and water use efficiency, it is further concluded that increased levels of atmospheric CO_2 may actually be essential to our future well-being.

26. Idso, S. B. CO_2 and climate: Where is the water vapor feedback? Arch. Met. Geoph. Biolk., Ser. B. (In press).

Results of previously published studies are used to demonstrate that th water vapor feedback mechanism, so important to the calculation of a significant climatic effect for a doubling of the atmospheric CO_2 concentration, appears to be counter-balanced by another feedback mechanism of opposite sign. At high temperatures (low latitudes) the two effects essentially negate each other; while at lower temperatures (high latitudes) their respective strengths have yet to be determined. What is known to date tends to indicate that the climatic consequences of increasing the atmospheric carbon dioxide concentration will be significantly less than what is routinely predicted by the general circulation models of the atmosphere in use today.

27. Idso, S. B. Climatic effects of atmospheric CO_2. Science. (In press).

An analysis of published temperature trends of the last century shows that the real world has been responding just the opposite of the predictions of the general circulatons models of the atmosphere that predict large-scale global warming as a result of the planet's increasing CO_2 concentration.

28. Idso, S. B. An intriguing climatic observation. J. Rech. Atmos. (In press).

It is pointed out that between 1966 and 1980, satellite photos show Northern Hemisphere snow cover to have increased by over 3,000,000 square kilometers, in contradiction to the predictions of the general circulation models of the atmosphere that have been applied to the CO_2-climate question.

29. Idso, S. B. On trusting models or observations. Atmos. Environ. (In press).

Empirical evidence and model caveats are cited to indicate that the predictions of the CO_2-climate modeling community are not to be trusted at their present crude level of sophistication.

30. Idso, S. B. Reply to A. J. Crane's "Comments on recent doubts about the CO_2 greenhouse effect." J. Appl. Meteorol. 21:748.

Arguments put forth by A. J. Crane to discredit the empirical approach to determining the effects of CO_2 on climate are refuted.

31. Kimball, B. A., and Idso, S. B. Increasing atmospheric CO_2: Effects on crop yield, water use and climate. Agric. Water Mgt. (In press).

Probable effects of increasing global atmospheric CO_2 concentration on crop yield, crop water use, and world climate are discussed. About 430 observations of the yields of 37 plant species grown with CO_2 enrichment were extracted from the literature and analyzed. CO_2 enrichment increased agricultural weight yields by an average 36%. Additional analysis of 81 experiments which had controlled CO_2 concentrations showed that yields will probably increase by 33% with a doubling of atmospheric CO_2 concentration. Another 46 observations of the effects of CO_2 enrichment on transpiration were extracted and averaged. These data showed that doubling of CO_2 concentration could reduce transpiration by 34%, which combined with the yield increase, indicates that water use efficiency may double.

Several theoretical models have predicted that the doubling of atmospheric CO_2 concentration will increase the earth's temperature by 2-4 C, which could seriously disrupt agricultural production. More recent empirical evidence suggests that the warming may only be about 0.25 C, so the primary effects on agriculture are likely to be the beneficial increases in crop yields and water use efficiency.

32. ANZA 82:

Anza wheat was planted on the U. S. Water Conservation's "backyard" field plots on 16-17 December 1981. In addition to standard micrometeorological parameters such as global, reflected and net radiation, soil temperatures and wet and dry bulb temperatures, evapotranspiration was monitored with three permanent weighing lysimeters, and water depletion was measured three times a week via a neutron scattering technique. Agronomic parameters were obtained on a twice weekly basis. These included stage of growth (using the Zadok's growth scale), plant height, number of green leaves, number of live tillers, green leaf area, and biomass.

Remote sensing observations were modeled after those employed in previous experiments. Radiant canopy temperatures were estimated from 1330 to 1400 using portable infrared thermometers. Canopy reflectance was measured using a 4-band Exotech radiometer with bandpass characteristics approximating those of the Multispectral Scanner on LANDSAT satellites.

Data analysis is not complete; however, Table A lists preliminary results based on an average of four, 1 by 3 meter harvest areas within each of the 18 experimental plots. Final grain yield varied two-fold from 355 to 768 gm/m^2. Figure C shows that final yield was significantly correlated with the average Crop Water Stress Index (Jackson, 1981) calculated over the interval from plant head emergence until the beginning of the hard dough stage. Yield components will be examined further to determine to what extent they were influenced by the temporal sequence of CWSI values, a stress indicator reflecting the amount and timing of irrigation applications.

SUMMARY AND CONCLUSIONS:

Calculated evapotranspiration (ET) using remotely sensed surface temperature in energy balance models, agreed quite well with measured ET for a variety of crops at several locations in the Western United States. To convert these instantaneous ET calculations to daily totals, coefficients were derived from theoretical considerations that can be applied from 60 degrees south to 60 degrees north latitude. The goal of remotely obtaining sufficiently accurate estimates of ET over large areas is closer than ever before. The problem still exists, however, of obtaining air temperature and net radiation remotely.

A crop water stress index (CWSI) was highly correlated with xylem water potential, leaf diffusion resistance and net photosynthesis for cotton. However, the xylem water potential of cotton transpiring at the potential rate was found to be a function of the atmospheric vapor pressure deficit. It is now possible to obtain accurate estimates of traditional plant stress indicators (xylem water potential and leaf diffusion resistance) rapidly and over large areas using remotely sensed plant temperature and dry- and wet-bulb air temperatures.

Satellite data were simulated using a radiative transfer model and ground measured reflectances. A method was developed to adjust for atmospheric effects on a pixel by pixel basis, thus accounting for spatial variability of aerosols. Several commonly used vegetation indices were then examined for their ability to discriminate vegetation and to detect stress, under clear and turbid atmospheres. It was found that atmospheric conditions may cause a delay of from 3 to 7 days in the discrimination between drought-stressed and unstressed wheat.

Data from a number of sources are presented to indicate that (1) there was a gradual increase in global atmospheric CO_2 concentration from about 1860 to 1945, (2) there has been a much more rapid rate of increase in atmospheric CO_2 concentration from 1945 to the present, (3) the most recent trend of global surface air temperature during this period of rapid CO_2 increase has been downwards, in conradiction to the predictions of the most sophisticated general circulation models of the atmosphere in use today, (4) this downward trend in surface air temperature has been most pronounced in northern latitudes, also in contrast to the model predictions, and (5) the downward temperature trend has been greater in summer than in winter, again in contradiction to the models. It is thus concluded that the theoretical numerical models of the atmosphere are grossly in error in their predictions of future CO_2 effects on world climate, as is also suggested by several recent empirical studies. Consequently, since global population continues to climb and require more and more food, and since elevated CO_2 concentrations have been documented to enhance crop productivity (as much as 1/3) and water use efficiency (up to a doubling), it is further concluded that increased levels of atmospheric CO_2 may actually be essential to our future well-being.

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TABLE A. Plant density and yield components for Anza wheat grown in Phoenix during 1981-82.

	Plants per m^2		Rows/	Grain Yield gm/m^2		No. Heads/m^2		No. Heads/	Wt/1000 Seeds		No. Seeds/
Plot	$\bar{x}$	se	m^2	$\bar{x}$	se	$\bar{x}$	se	Plant	$\bar{x}$	se	Head
1A	71.4	4.20	5.4	768.2	25.01	578.2	24.65	8.10	32.84	0.40	40.45
1B	82.7	2.10	5.6	722.5	8.43	587.3	10.26	7.10	32.92	0.59	38.55
1C	82.0	3.37	5.5	586.3	20.06	534.1	6.35	6.51	30.24	0.60	36.32
2A	69.0	1.98	5.0	719.5	11.69	52.6	8.78	7.57	32.56	0.50	42.31
2B	74.6	3.72	5.3	354.8	10.20	529.9	15.37	7.10	20.30	0.49	33.00
2C	78.4	4.31	5.3	582.1	14.19	427.9	8.43	5.45	39.52	0.31	34.41
3A	69.2	3.40	5.0	646.3	10.44	519.2	10.37	7.50	29.92	0.56	41.62
3B	76.1	1.79	5.2	561.4	6.71	504.2	13.98	6.63	28.70	0.62	38.77
3C	62.2	3.70	5.1	458.4	18.02	383.3	12.19	6.16	34.12	0.66	35.06
4A	62.7	2.34	5.0	601.5	19.53	472.6	8.02	7.54	39.32	0.49	32.36
4B	52.0	2.79	5.0	635.9	4.01	477.4	13.17	9.18	32.18	0.59	41.40
4C	57.7	4.02	4.8	587.4	13.50	455.0	22.97	7.89	32.44	0.30	39.77
5A	60.4	1.24	5.3	715.9	15.26	487.4	13.21	8.07	35.66	0.44	41.18
5B	59.5	1.71	5.3	601.2	9.89	416.2	4.90	7.00	37.66	0.31	38.33
5C	61.4	0.33	5.2	597.0	11.84	444.6	14.12	7.24	33.58	0.56	39.87
6A	56.5	1.67	5.5	681.4	23.36	552.2	14.38	9.77	29.98	0.21	41.17
6B	74.5	2.63	5.7	691.2	19.18	523.8	6.37	7.03	34.76	0.39	37.97
6C	73.3	4.60	5.5	606.3	20.84	486.1	15.26	6.63	34.74	0.04	35.91

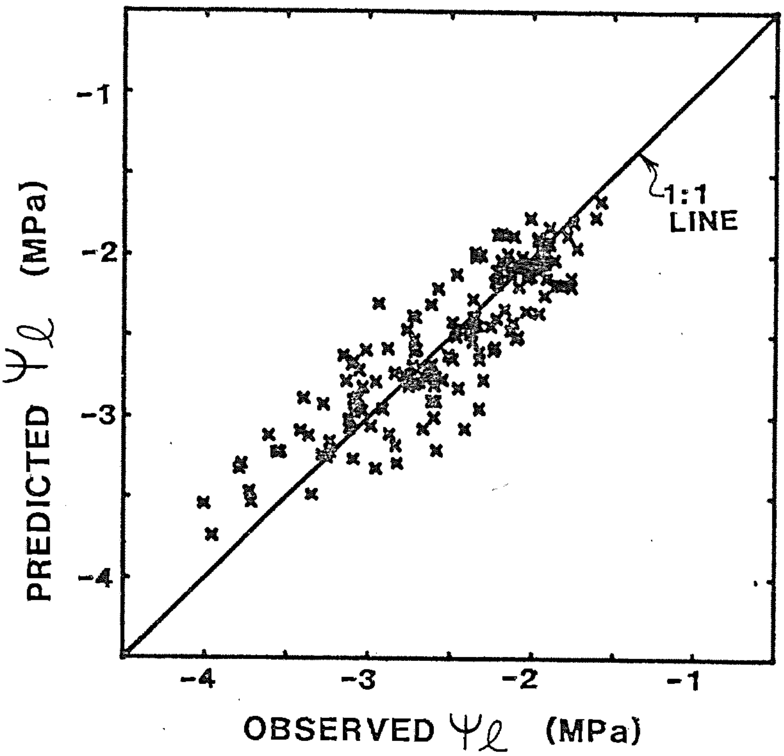

Figure A. A comparison of observed cotton leaf water potentials and those predicted from remotely sensed crop canopy temperatures, age of the crop and ambient vapor pressure deficits.

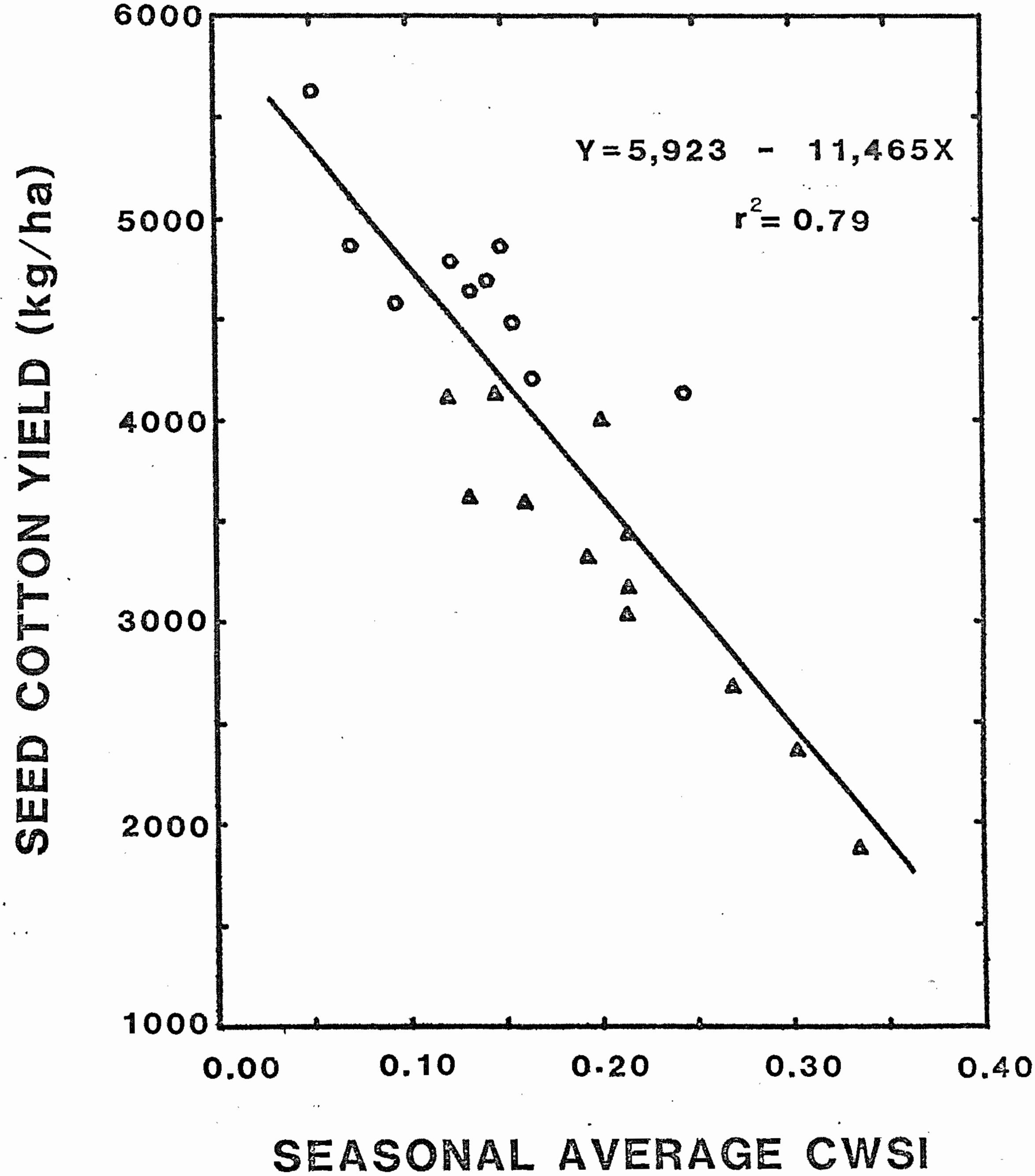

Figure B. Cotton yield versus the average daily CWSI measured over an 88-day period from first square until 2 weeks following the last irrigation for Phoenix (triangles). A comparable interval was averaged for Westlake Farms, CA, data and is shown as circles.

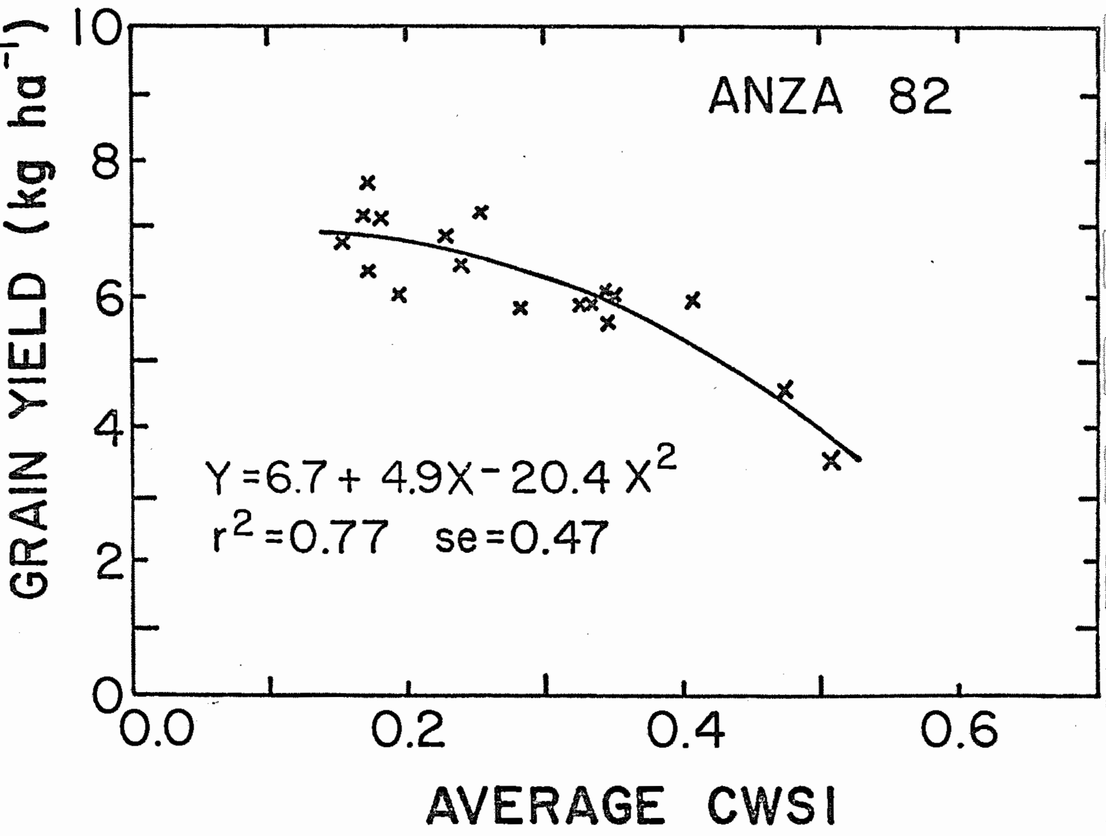

Figure C. Grain yield (dry weight basis) of Anza wheat grown at Phoenix during 1982 versus the average daily CWSI calculated by the Jackson approach (1982) over the heading period.

TITLE: CONSTRUCTION AND TESTING OF A SMALL, CLOSED PORTABLE CHAMBER FOR FIELD PHOTOSYNTHETIC MEASUREMENT OF SINGLE PLANTS

NRP: 20760 CRIS WORK UNIT: 5510-20760-004

INTRODUCTION

Photosynthetic measurements give a good indication of the physiological condition and response of plants to the environment and are useful in making estimates of biomass yield. Such measurements were found to be difficult to make with existing equipment on individual guayule (Parthenium argentatum) leaves because of their small size. Therefore, the whole plant was considered as a unit which required the use of chamber-type enclosures. Musgrave and Moss (1961) determined photosynthetic and transpirational rates of corn (Zea mays) with enclosed chambers (2.75^W x 1.50^L x 3.65^H) that required cooling when one-hour runs were made. Sestak, et al. (1971) discuss other closed-chambers and although there are limitations to this type of system, we, nevertheless, considered it as an alternative to the continuous monitoring system which requires elaborate instrumentation. Our initial interest was to get relative rather than absolute photosynthetic behavior and thus a closed-chamber system suitable for the guayule plant was built and tested for estimating photosynthesis.

PROCEDURE

A rectangular, portable plant chamber (48 x 48 x 100 cm) was constructed from 0.625 cm clear Plexiglass (Fig. 1). The walls and roof were cemented together with 2.5 x 2.5 cm polyvinyl chloride (PVC) angles to provide strength and to prevent air leakage. To isolate the plant from the soil a special bottom for the chamber was constructed from 1.5 cm thick plyboard cut to 54.5 cm x 54.5 cm to which an 34 cm x 34 cm opening was made in the center. This allowed the floor to be slipped over the plant, and then the chamber placed on the flooring. To minimize air interchange from the inside of chamber to the surrounding atmosphere a closed cell foam mounting tape was cemented to the board. A piece of 65 cm x 65 cm PVC film with slit cut from the center to one side was wrapped around the stem of a plant. A fold could be made so that the film laid snuggly on the wood floor and the chamber could be placed on the film-foam surface to seal the bottom. The chamber weighed 18 kgs (40 lbs) and was easily handled by one person.

Air was circulated within the chamber by a 12 volt DC, 15.2 cm (6 in) auto fan with a 5.1 m^3/min (180 cfm) delivery capacity in free air. The fan blade was installed inside and the motor placed outside the chamber to prevent any introduction of ozone from the electric motor. To assure the presence of adequate air circulation, air movement inside the chamber was measured with a hot wire anemometer. The air movement was 0.24 m/s inside the chamber, which is sufficient to minimize the boundary layer resistance (R_a) to a value of 0.073 sec/cm.

The inner chamber temperature was measured with a 0.009 cm copper-constantan thermocouple. The air temperature increased from 2 to 5 when the external air temperature was in the 70° to 110° C range during a tw minute period.

The leakage rates were determined by injecting CO_2 into the chamber and following the CO_2 concentration change or decrease as a function of tim (Businger, 1963; Kimball, 1981). The leakage rate in the chamber was estimated to be 1% error after a 4.6 minute exposure, which is acceptable because the plant is enclosed for only two minutes.

In actual operation, the chamber floor and isolating film was installed first around the plant; then, the chamber placed over the plant by one er son which took less than 10 seconds. Immediately following enclosure, duplicate 10 cc gas samples were simultaneously taken (C_i) with a pair of syringes and after a two-minute period another set of samples (C_o) were obtained. The syringes were stored in insulated containers and transported to the laboratory for analysis. A modified Clegg, et al. (1978) infrared analysis technique (Nakayama and Rasnick, 1980) was used for the CO_2 analysis of the gas samples.

Net photosynthesis was calculated using the following relation:

$$\text{net photosynthesis} = [(C_i - C_o) \cdot K \cdot V/t] / 10^6$$

where K = the constant of conversion of volume of CO_2 to milligram (22.4 liter of CO_2 at 0 C and one atmosphere pressure is equal to 44,000 milligram of CO_2) or

$$K = [44{,}000 \text{ mg } CO_2 / 22.4 \text{ liters } CO_2 \times (273/298)] = 1799.5 \text{ l-mg}$$

$$V = \text{chamber volume } [L \cdot W \cdot H] / 1000 \text{ cc} = [48 \times 48 \times 100] / 1000$$

$$= 230.4 \text{ liters.}$$

t = time lapse for sample

Photosynthesis was measured on individual 2-1/2-year-old guayule plants of variety 11591 at approximately 1000 hour on experimental plots in Phoenix that were established for determining plant behavior at different irrigation levels.

RESULTS AND DISCUSSION:

Average net photosynthetic rates of four plants grown under three soil moisture regimes are illustrated in Fig. 2, with the soil water content an irrigation dates noted in Fig. 3. The same plants were used throughout th study period.

The higher photosynthetic rate shown by the plants in the medium compared to the dry and wet treatments was likely the result of irrigation prior to sampling. The reverse situation occured when the dry and wet plots were irrigated and the medium plot left unirrigated for the succeeding set of measurements in latter September. Thus, the moisture availability is one of the critical factors affecting photosynthesis. Radiation and temperature decreases starting in the latter part of October caused decrease in photosynthesis. The relative magnitude of photosynthesis of the plants in the different treatments reflect the moisture levels in the soil.

SUMMARY AND CONCLUSIONS:

A closed chamber system for measuring photosynthesis of individual plants in the field was built and tested. Photosynthesis could be measured in a two-minute period after plant enclosure so that reliable data could be obtained without damage to the plants. Photosynthetic rates of the guayule plants reflected the moisture status of the soil with higher rates occurring at higher moisture levels.

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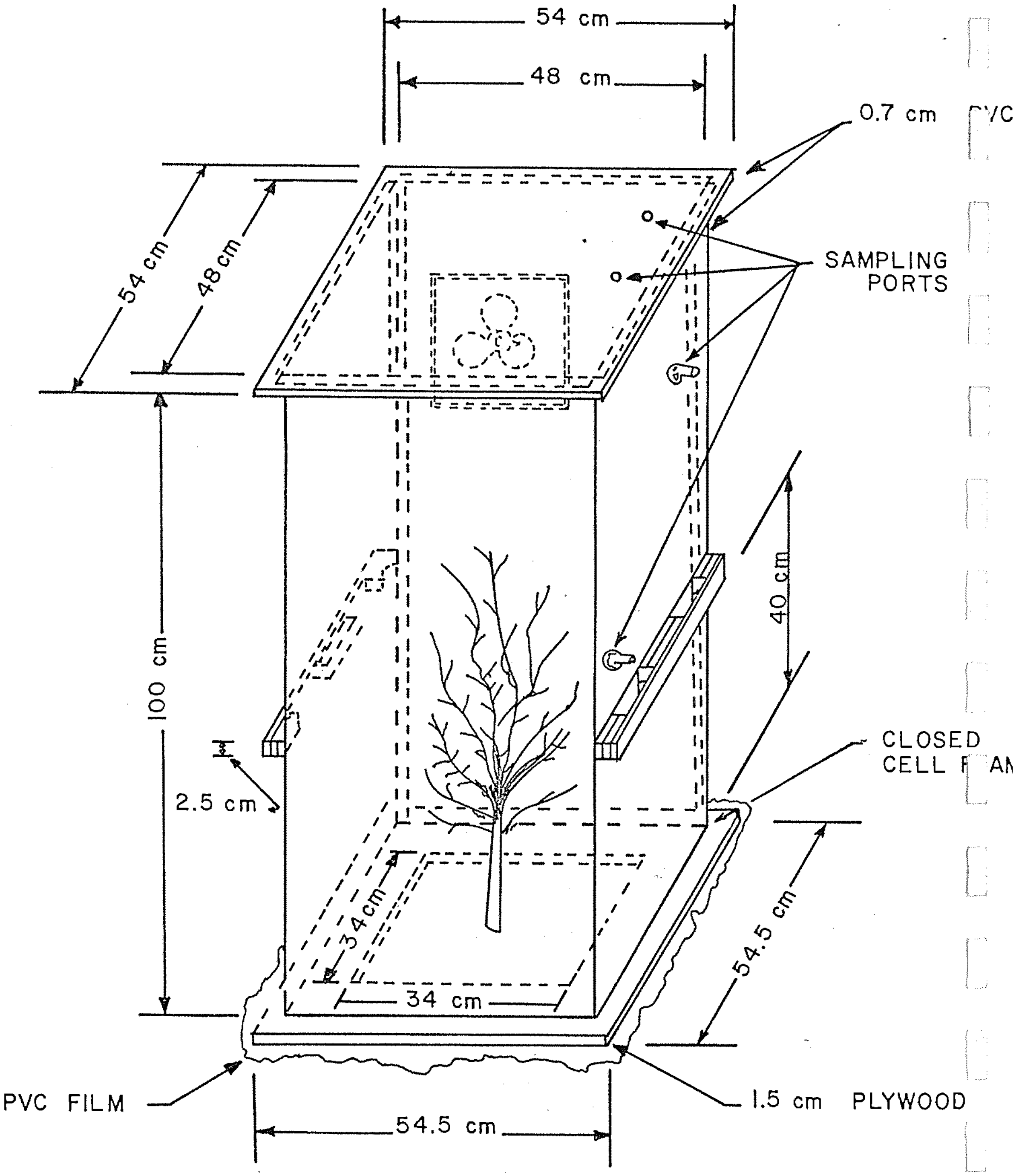

Figure 1. Construction detail of closed-chamber for measuring photosynthesis.

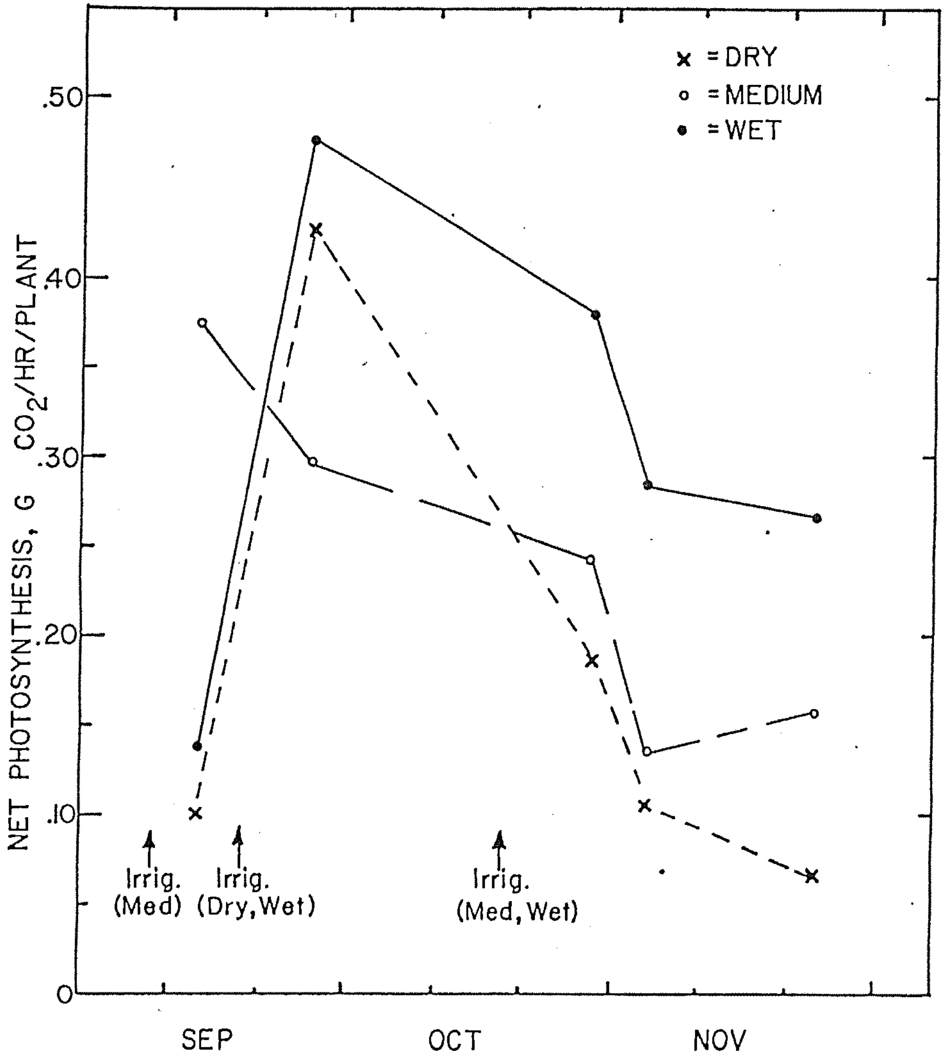

Figure 2. Net photosynthetic rates of guayule plants under different soil moisture regimes.

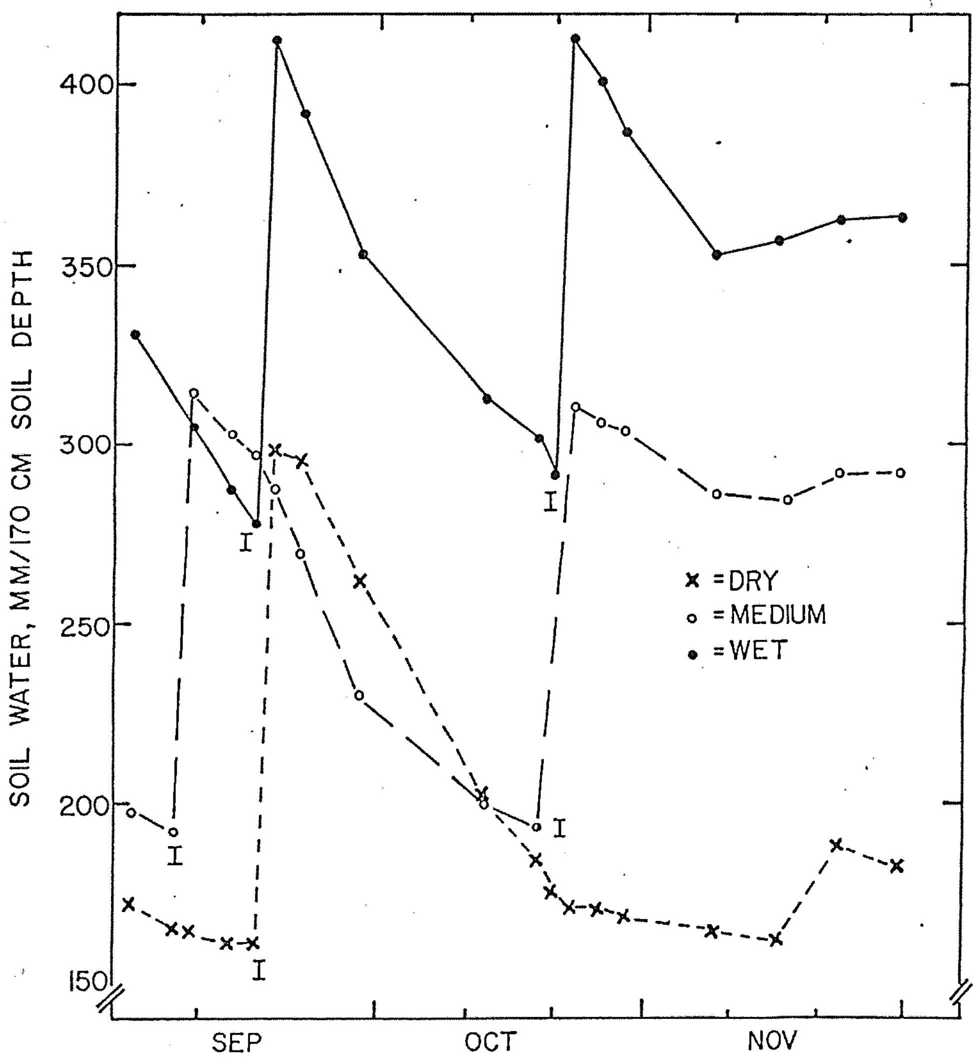

Figure 3. Soil water contents for the 170 cm depth for the various irrigation treatments. (I = irrigation).

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

NRP: 20760 CRIS WORK UNIT: 5510-20760-004

INTRODUCTION:

The benefits from growing plants in unventilated greenhouses are potentially very large. The greenhouse cover slows the loss of water, so plants can be grown in arid regions. High light intensity and long duration of sunshine in such regions are conducive to high crop yields, particularly when the greenhouses are enriched with CO_2. Therefore, this project was started with the objectives: (1) to design, test, and evaluate coolers for unventilated greenhouses under summer conditions, (2) to design, test, and evaluate methods of solar energy storage as a means to achieve satisfactory heating in winter and cooling in summer of unventilated greenhouses, (3) to evaluate the yield responses attainable with CO_2 enrichment in unventilated greenhouses, and (4) to evaluate alternative sources of CO_2 for fertilizer.

During 1982 much progress was made in evaluating one particular type of cooler, night sky radiators, as part of Objective 1 as will be discussed later. A method to calibrate infrared thermometers at low (-70C to 0C) temperatures was also developed as part of this effort. Progress toward Objective 2 consisted of adapting the MEB computer model to the new Hewlett-Packard 1000 computer. A set of eight standard examples of different greenhouse systems was developed as an aid to debugging when the model is implemented onto new computer systems. The model is now being implemented at one location in New Zealand, and requests have been received from several other locations around the world. The user's manual has now (finally) been completely written, and distribution to interested parties can begin as soon as typing and corrections are finished.

Progress toward Objective 3 consisted mainly of trying to implement a large field CO_2 enrichment experiment using 36 open-top chambers. The objectives would be to evaluate the effects of atmospheric CO_2 enrichment on productivity, water use efficiency, and photosynthesis of crop plants under normal and stress levels of water and nitrogen. However, the experiment as planned was not feasible due to the cost of the large amounts of CO_2 required. Therefore, much effort was expended toward Objective 4--finding alternative sources of CO_2 which would be much less expensive than pure commercial liquid CO_2. The only possible source of inexpensive pure CO_2 (an ammonia plant) closed because of natural gas pricing. Numerous contacts were made to find sources of relatively clean combustion gas, and two sites were located which also had suitable land nearby to conduct the experiment. Analyses were then made of the combustion gases from the exhaust stacks, only to find levels of ethylene and other contaminants that were high enough to require removal before such an experiment could be conducted with confidence. Therefore, after much discussion, it was decided to conduct a mini-experiment this coming year using pure commercial CO_2 with only six chambers. Only optimum levels of water and nitrogen will be used, thereby reducing the number of treatments. As time permits, an effort will be made to test ways to clean combustion gases so that a larger experiment could be conducted in the future using this inexpensive source of CO_2.

I. COOLING PERFORMANCE AND EFFICIENCY OF NIGHT SKY RADIATORS

Introduction.

Every night the Earth's surface is cooled by radiation to the night sky. The phenomenon is a commonly accepted experience, but relatively little work has been done to make greater use of this process for practical cooling purposes. Any such cooling method which consumes little fossil energy or water deserves a full examination of its potential.

In 1969 Hay and Yellott proposed the use of movable insulation which can shield a structure from solar radiation during the day and can be removed at night to expose the structure directly to the night sky. A method to enhance night radiation directly was proposed by Head (1959, 1962), Catalanotti et al. (1975), and Bartoli et al. (1977). They suggested the use of selective surfaces which make use of the fact that the atmosphere has a relatively high transmittance to thermal radiation in the 8-14 μ "window" but behaves nearly like a blackbody at wavelengths outside of the window. Therefore, an ideal radiator would be perfectly black (emittance of 1.0) within the 8-14 μ band in order to have maximum power in the atmospheric window, and it would also be perfectly reflective (reflectance of 1.0) outside the atmospheric window in order to reflect the radiation coming down from the atmosphere. Such a radiator would also require a transparent cover to insulate the cold surface from the air above. Catalanotti et al. and Bartoi et al. constructed a selective radiator using polyvinyl-fluoride (TEDLAR) deposited on aluminum with polyethylene cover, and they achieved 10-15C depression of the radiator surface temperature below air temperature.

In 1978 Harrison and Walton suggested that commercial white paint containing the pigment TiO_2 could be used as a selective radiator coating and they reported a 15C depression below air temperature. Then in 1981 Harrison presented much cooling performance data with depressions from 1 to 12C below air temperature, depending on humidity. He also presented some theoretical curves which appeared to represent his data fairly well. However, Mitchell and Biggs (1979) presented a spectral curve for TiO_2-based white paint which showed it was rather black with a reflectance of 0.15 at thermal wavelengths. This curve casts doubt not only on the selectivity of white TiO_2 paint but also on the accuracy of the theoretical curves of Harrison (1981). Mitchell and Biggs also presented cooling performance for two small huts, one with a blackbody (white TiO_2 paint) roof and the other with a selective (polyvinyl-fluoride on aluminum) roof. The blackbody roof performed slightly better than the selective, and they concluded that a selective surface has a little advantage unless the radiator surface temperature is significantly below air temperature.

Several of the above authors, as well as Johnson (1973), Berdahl and Martin (1978, 1981), Blanpied et al. (1982), and Erickson and Granquist (1982), have made theoretical computations of the potential for radiative cooling to the night sky. However, the theories require rather detailed information about the thermal radiative properties of the atmosphere as well as of the radiator surface and its cover. Moreover, the authors have not provided a definition of radiator efficiency which can be used for making practical comparisons between radiators. I shall derive such a definition of efficiency based on a simple sky radiation model and demonstrate its application.

Theory

1. Prediction of Radiator Surface Temperatures.

The night sky radiator has a surface which is exposed to the night sky and which is insulated from the ambient air by a partially transparent cover that produces a stagnant air space. The surface is characterized by its emittances, ε_{sw} and ε_{so}, which are effective average values for the thermal emittances within and outside, respectively, of the 8-14 μ atmospheric window band. Of course, its reflectances, ρ_{sw} and ρ_{so}, are 1 minus the corresponding emittances. Similarly, the cover is characterized by transmittances, τ_{cw} and τ_{co}, and reflectances, ρ_{cw} and ρ_{co}, and the insulating air space has a heat transfer coefficient of $U(Wm^{-2}C^{-1})$. Energy is supplied to the bottom of the surface at a rate of $Q(Wm^{-2})$ by some arbitrary means such as conduction from a source below, convection from a heat transfer fluid, or (as in our experiments), conduction from an electrical heater. Energy is radiated from the surface, the cover, and the sky at rates of R_{sw}, R_{so}, R_{cw}, R_{co}, and R_{aw}, R_{ao} (Wm^{-2}) where w and o again refer to within and outside the 8-14 μ atmospheric window. Writing an energy balance on the surface of the radiator produces the following equation:

$$R_{aw}\beta_{aw} + R_{ao}\beta_{ao} + R_{sw}\beta_{sw} + R_{so}\beta_{so} + R_{cw}\beta_{cw} + R_{co}\beta_{co} + U(T_a - T_s) + Q = 0 \qquad (1)$$

where:

$$\beta_{aw} = \tau_{cw}\ \varepsilon_{sw}/(1 - \rho_{sw}\rho_{cw})$$

$$\beta_{ao} = \tau_{co}\ \varepsilon_{so}/(1 - \rho_{so}\rho_{co})$$

$$\beta_{sw} = [\rho_{cw}\ \varepsilon_{sw}/(1 - \rho_{sw}\rho_{cw})] - 1$$

$$\beta_{so} = [\rho_{co}\ \varepsilon_{so}/(1 - \rho_{so}\rho_{co})] - 1$$

$$\beta_{cw} = \varepsilon_{sw}/(1 - \rho_{sw}\rho_{cw})$$

$$\beta_{co} = \varepsilon_{so}/(1 - \rho_{so}\rho_{co})$$

In the above β's, the factors of the form $(1/(1 - \rho_s\rho_c))$ account for multiple reflections of the radiation fluxes. These reflections produce an infinite geometric series shown on the left-hand side of Equation 2 which is equal to the more convenient closed form on the right-hand side (Jolley, 1961). Thus, wherever the factor $1/(1 - \rho_s\rho_c)$ appears, the reader should remember that the whole series of multiple reflections is being evaluated:

$$1 + \rho_s \rho_c + (\rho_s \rho_c)^2 + (\rho_s \rho_c)^3 + \ldots \infty = 1/(1 - \rho_s \rho_c) \quad (2)$$

In Equation 1 the first two terms account for sky radiation absorbed by the cover, the third and fourth for radiation emitted by the surface, and the fifth and sixth for cover radiation absorbed by the surface. The seventh term accounts for conduction through the insulative air layer, and the eighth is the external energy supplied.

The sky radiation inside and outside the atmospheric window is defined by

$$R_{aw} = \varepsilon_{aw} f_{aw} \sigma T_a^4 \qquad R_{ao} = \varepsilon_{ao} f_{ao} \sigma T_a^4 \quad (3)$$

Idso (1981b) presented an equation for predicting the 8-14 μ clear sky emittance in the zenith direction, ε_{awz}, and also a correction (1981a) to convert zenith to hemispherical emittance.

$$\varepsilon_{awz} = 0.24 + 2.98 \times 10^{-6} e_a^2 \exp(3000/(T_a + 273.16))$$

$$\varepsilon_{aw} = \varepsilon_{awz} (1.4 - 0.4 \varepsilon_{awz}) \quad (4)$$

Equations 4 depend only on measurements of ambient air vapor pressure, e_a (kPa), and temperature, T_a(c), and they accurately account for the effect of water dimer molecules in the atmosphere, which many other models do not. For cloudy conditions, an accounting can be made for the cloud contribution (Kimball et al., 1981). The sky is assumed to be black outside the window so that $\varepsilon_{ao} = 1.0$. The fraction of radiation the 8-14 μ band can be computed for any given temperature (in degree C) from

$$f_w = 0.34906 + 1.2495E\text{-}3T - 0.91397E\text{-}5T^2 \quad (5)$$

Equation 6 was obtained by fitting a quadratic ($R^2 = 0.9990$) to values calculated from Table 2 of Harrison (1960) from -90 to +70C. Within the 10-40C temperature range, f_w changes only slightly (Figure 1). The fraction of radiation outside the window, f_o, is defined by: $f_o = 1 - f_w$

The cover is assumed to be at air temperature because convection above the cover should be relatively great compared to the stagnant air under the cover (Catalanotti et al., 1975). Then the radiation emitted by the cover can be computed from known emittances of the cover

$$R_{cw} = \varepsilon_{cw} f_{aw} \sigma T_a^4 \qquad R_{co} = \varepsilon_{co} f_{ao} \sigma T_a^4 \quad (6)$$

The radiation emitted from the surface could be computed from the surface temperature, if it were known. Generally, it is an unknown, but Equation 1 can be solved to obtain the surface temperature. The surface radiation is defined as:

$$R_{sw} = \varepsilon_{sw} f_{sw} \sigma T_s^4 \qquad R_{so} = \varepsilon_{so} f_{so} \sigma T_s^4 \quad (7)$$

Equations 7 can be linearized following Kimball (1981). Let

$$\delta_{sw} = 4 \varepsilon_{sw} f_{sw} \sigma (T_s^o)^3 \qquad \delta_{so} = 4 \varepsilon_{so} f_{so} \sigma (T_s^o)^3 \quad (8)$$

where T_s^o is an "old" estimate of T_s. Then

$$R_{sw} \cong R_{sw}^o + \delta_{sw} (T_s - T_s^o) \quad R_{so} \cong R_{so}^o + \delta_{so} (T_s - T_s^o) \tag{9}$$

where R_{sw}^o and R_{so}^o are the thermal radiations emitted from the surface at T_s^o. Letting

$$Y_{sw} = R_{sw}^o - \delta_{sw} T_s^o \quad Y_{so} = R_{so}^o - \delta_{so} T_s^o \tag{10}$$

Equation 1 can be solved to obtain T_s explicitly.

$$T_s = \frac{-\beta_{sw}Y_{sw} - \beta_{so}Y_{so} - R_{aw}\beta_{aw} - R_{ao}\beta_{ao} - R_{cw}\beta_{cw} - R_{co}\beta_{co} - UT_a - Q}{\beta_{sw}\ \delta_{sw} + \beta_{so}\ \delta_{so} - U} \tag{11}$$

Equation 11 is an iterative-type equation. By first making an initial guess for T_s^o in Equations 7, 8, 9, and 10, an estimate for T_s is obtained from Equation 11. Then setting T_s^o equal to this estimate of T_s and repeating the process, a convergent value for T_s is rapidly found (Kimball, 1981).

2. Night Sky Radiator Efficiency

The performance of a night sky radiator can be normalized with respect to a "perfect" radiator. The cover of such a radiator would be transparent so that $\tau_{cw} = \tau_{co} = 1$, $\varepsilon_{cw} = \varepsilon_{co} = 0$, and $\rho_{cw} = \rho_{co} = 0$. Furthermore, it would be perfectly insulated so that $U = 0$. As discussed in the introduction, the surface of this ideal radiator would be highly reflective outside the atmospheric window but black inside the window so that $\rho_{so} = 1$, $\rho_{sw} = 0$, $\varepsilon_{so} = 0$, and $\varepsilon_{sw} = 1$. Substituting these values into Equations 1 and 7

$$Q + \varepsilon_{aw} f_w \sigma T_a^4 - f_w\ \sigma\ T_s^4 = 0 \tag{12}$$

If energy is supplied to the radiator surface at a rate such that the surface temperature equals air temperature, then

$$Q = f_w(1 - \varepsilon_{aw})\ \sigma T_a^4 \tag{13}$$

This rate of energy addition is dependent only on the atmosphere; therefore, we can define

$$R_I = f_w\ (1 - \varepsilon_{aw})\ \sigma T_a^4 \tag{14}$$

to be the power at which the atmosphere can receive energy from an ideal radiator. For clear sky conditions, ε_{aw} can be calculated from Equations 4; therefore, R_I is also easily predicted for clear sky conditions. R_I is plotted as a function of air temperature and vapor pressure in Figure 2 for clear skies. For typical operating conditions of T_a = 20C and e_a = 1 kPa, R_I = 91 W/m^2.

The effect of clouds on R_I depends upon the amount and type of clouds, upon cloud temperature, and upon air temperature and vapor pressure

(Kimball et al., 1982). The model presented by Kimball et al. (1982) could be used to predict rather accurately the effects of clouds on R_I for any set of given cloud conditions. This study was concerned more with the theory of operation of night sky radiators, so more attention was given to clear sky conditions. However, a simple crude estimate of cloud effects can be extracted from Kimball et al. They showed that the increase in sky radiation due to clouds for overcast conditions could range from 0 to percent, and the increase was proportional to cloud amount. For Phoenix conditions, the increase for overcast conditions averaged about 16 percent. Assuming this increase to occur entirely within the atmospheric window means that ε_{aw} must increase by roughly 90 percent for an air temperature and vapor pressure of 20C and 1 kPa, respectively. Thus, a crude estimate of R_I for cloudy conditions could be obtained from

$$R_{IC} = f_w [1 - \varepsilon_{aw} (1 + 0.9C)] \sigma T_a^4 \qquad (15)$$

where C is the fraction of the sky covered by clouds.

The ideal radiator power is a useful parameter for standardizing night sky radiator tests performed under different conditions, as can be seen from the following. Ignoring reflections and absorption by the cover, Equation 1 can be written

$$Q - (\varepsilon_{sw} f_w + \varepsilon_{so} f_o) \sigma T_s^4 + (\varepsilon_{aw} \varepsilon_{sw} f_w + \varepsilon_{ao} \varepsilon_{so} f_o) \sigma T_a^4 + U(T_a - T_s) = 0 \qquad (16)$$

Rearranging

$$Q = -f_w \varepsilon_{sw} (\varepsilon_{aw} \sigma T_a^4 - \sigma T_s^4) - f_o \varepsilon_{so} (\varepsilon_{ao} \sigma T_a^4 - \sigma T_s^4) - U (T_a - T_s) \qquad (17)$$

Noting that $\varepsilon_{ao} \simeq 1$, approximating $\sigma T_a^4 - \sigma T_s^4$ with $4 \sigma \overline{T}^3 (T_a - T_s)$, and dividing by R_I, yields:

$$Q/R_I = \varepsilon_{sw} - [4 \sigma \overline{T}^3 (f_w \varepsilon_{sw} + f_o \varepsilon_{so}) + U] [(T_a - T_s)/R_I] \qquad (18)$$

and when Q = 0,

$$T_a - T_s = R_I \varepsilon_{sw} / [4 \sigma \overline{T}^3 (f_w \varepsilon_{sw} + f_o \varepsilon_{so}) + U] \qquad (19)$$

Equation 18 defines a line with an intercept of ε_{sw} and a slope of $[4 \sigma \overline{T}^3 (f_w \varepsilon_{sw} + f_o \varepsilon_{so} + U)]$. The intercept is an "efficiency" of the radiator when $T_s = T_a$ and it depends on the surface properties, not on the atmospheric conditions of the test. It is analogous to the way the performance of solar collectors is normalized by dividing by the intensity of solar radiation (Beckman et al., 1977). The slope is only weakly dependent upon temperature ($4 \sigma \overline{T}^3$ is plotted in Figure 1), enabling the maximum temperature depression of the radiator surface below air temperature (when Q = 0) to be predicted from Equation 19. In practice, the effect of absorption and reflections by the cover degrade the performance predicted by Equations 18 and 19. However, if Q/R_I is plotted against $(T_a - T_s)/R_I$

the curves obtained by powerful radiators should be above those of less powerful radiators, even though the tests may have been performed under somewhat different sky conditions. Moreover, the curves are nearly linear.

3. Experimental Methods

To obtain actual measurements of the performance of night sky radiators, four radiators were constructed, each with different thermal radiative properties. They were constructed from 6 extruded aluminum fin plates snapped over a serpentine of copper tubes, such as are used for solar collectors. The length of each fin was 96.6 cm, and the 6 fins side-by-side had a width of 83.8 cm, to give an area of 0.810 m^2 for each radiator. These aluminum radiating surfaces were suspended in wooden boxes over 10 cm of fiberglass insulation which itself was over 6 cm of styrofoam insulation.

Electrical heating wires were snaked through the copper tubes in each of the radiators and connected to a variable transformer. Measurements were made of the heater resistances at various temperatures so that an accurately known value of external energy, Q, could be applied from measurements of transformer voltage and surface temperature.

One of the radiators was left as bare aluminum. Another was painted with a white TiO_2 paint such as described by Harrison and Walton (1978). Two of the radiators were painted with black paint. Three of the radiators were covered with polyethylene film, one of the black radiators being left uncovered. The covers were held level about 2 cm above the radiating surfaces by three monofilament nylon lines stretched across from side-to-side of the boxes.

Two thermocouples were fastened to the underside of each radiator surface. One was positioned next to a copper tube and the other to the edge of a fin so that the effect of any temperature differences across the plate could be minimized and representative average temperatures obtained.

The 8-14 μ radiation from the sky was measured with an Everest Interscience Model 112 infrared thermometer, which has a KBr 8-14 μ band pass window and a 3-degree field-of-view focused at infinity. The thermometer was calibrated from -20 to +70C using an Advanced Kinetics Model EABB-250 extended area black body source. For calibration over a sky temperature range from -70 to 0C, a dry ice in ethanol bath was used. A stainless steel container with a conical neck welded to its top was submerged in the insulated bath to a level about 2 cm up on the neck. Three thermocouples were fastened to the bottom inside of the container, and the inside was painted black. During a calibration run, the thermometer was mounted in the neck so that it viewed the bottom of the container. Next, dry ice was dropped into the ethanol until a temperature near -70C was attained. Then the temperature from the thermocouples and the voltage output from the thermometer were recorded at 10-minute intervals as the bath slowly warmed to about 0C. Dry N_2 gas was bled slowly into the container to minimize condensation, and compressed air was bubbled into the bath near the bottom to stir the ethanol and minimize temperature gradients within the apparatus. The thermometer was slightly sensitive to ambient temperature, so the calibration runs were repeated at room temperatures of 15, 22, and 35C, and these data were used to correct sky temperature readings for changes in ambient air temperature.

In operation, the infrared thermometer was mounted in a container with an opening in the zenith direction. A fan pressurized the container slightly and blew air out the opening which prevented dust from settling on the thermometer. Measurements of zenith radiation were converted to hemispherical emittances using the Equation 4 correction.

Hourly measurements of the night sky radiator temperatures, 8-14 μ sky radiation, dry and wet bulb temperatures (Kimball and Mitchell, 1981), and wind speed were recorded on several nights between 16 April and 25 October 1982 when there was little danger of rain. The variable transformer was set to a desired voltage and connected to a timer which would turn on the heaters at about 04:15 in the morning. The hourly readings from any particular night were usually quite similar, and there were much larger changes from night-to-night as conditions changed. Therefore, only the 3 and 4 o'clock readings from each night when Q = 0 were selected for analysis and also the 5 o'clock readings when the heaters were on. Hourly cloud observation data were obtained from the National Weather Service, located about 7 km from our laboratory.

An attempt was also made to measure the conduction-convection heat transfer coefficient, U, using the method described by Catalanotti et al. (1975). Ice water was pumped through the copper tubes (heating wires removed) of the aluminum surface radiator to cool it far below equilibrium. Then the flow of water was stopped, and the rate of warming was measured. The process was repeated after placing aluminum plates just under all the radiator fins to add additional mass. The data were rather scattered but averaged about 2.7 $Wm^{-2}C^{-1}$ which agrees with the 3.5 $Wm^{-2}C^{-1}$ reported by Catalanotti et al. These values are about double the figure of 1.5 $Wm^{-2}C^{-1}$ listed by ASHRAE (1972) for the conductance of a stagnant horizontal 19-mm-thick air space with downward heat flow and low emittance surfaces. (The low emittance surface value was taken because it should contain only conduction-convection effects and not radiation.)

Results

1. Depression of Radiator Temperature Below Air Temperature

The depressions of the night sky radiator temperatures below air temperature are plotted against vapor pressure in Figures 3, 4, 5, and 6 for times when Q = 0 (heaters off) and skies were clear. There are considerable scatter in the data, but generally the depressions for the aluminum plate (Figure 3) averaged about 6C at vapor pressures near 0.5 kPa and about 2.5C for vapor pressures near 2 kPa. The depressions measured with the black uncovered radiator (Figure 6) were similar to those for the aluminum covered radiator. The white (Figure 4) and the black-covered (Figure 5) performed about twice as well as the aluminum or the black uncovered radiators as evidenced by average depressions of about 11C at vapor pressures of 0.5 kPa and about 6C at vapor pressures near 2 kPa.

Also shown on Figures 4-6 are theoretical curves computed using Equation 11 with parameters from Table 1 for various air temperatures. The pattern of the data tends to follow the curves, particularly for the white and the black-covered radiators. However, the scatter is too great to discern any air temperature dependence as predicted by the families of theoretical curves. The aluminum plate performed better than predicted, possibly because some unavoidable dust caused the surface emittance to be higher than the 0.14 used to compute the theoretical curves. Many of the depressions for the black uncovered plate are also smaller than predicted. A possible explanation for this is that often the convective heat transfer coefficient was larger than the 9.5 $Wm^{-2}C^{-1}$ predicted by the McAdams expression (Duffie and Beckman, 1974) for windspeeds of 1 m/s.

Figure 5 also has information superimposed upon it which is from Harrison and Walton (1978) and Harrison (1981) for TiO_2 white paint. The data of Harrison fall generally below the data obtained in this study, especially at vapor pressures above 1 kPa. The shape of his theoretical curves is qualitatively different. Presumably, they are based on an outside-of-window emittance, ε_{so}, of about 0.05. Using $\varepsilon_{so} = 0.05$ in Equation 11 produces the dotted curve. Considering (1) that the performances of black paint and the white paint radiators were similar in this study (Figures 4 and 5), (2) that using $\varepsilon_{so} = 0.95$ for black paint in Equation 11 produced curves that agreed with the data much better than using $\varepsilon_{so} = 0.05$ for "white" paint, and (3) that Michell and Biggs' (1979) measured values of ε_{so} are about 0.85 for white TiO_2 paint, I conclude that white TiO_2 paint behaves as if it is indeed black in the thermal region of the spectrum. Therefore, it is to be expected that Harrison's theoretical curves would not agree. However, the reason his performance data are lower remains a mystery.

2. Night Sky Radiator Efficiency

Figure 7 shows values of predicted ideal radiator performance, R_I, from clear sky Equation 14 plotted against corresponding measurements for various amounts of cloud cover. For clear sky conditions, the predicted and measured agreed fairly well with a correlation coefficient of 0.84. For cloudy conditions, the measured values were often less than predicted, but most of the time the predicted and measured values agreed fairly well. This agreement can be explained by the fact that the infrared thermometers used to measure sky radiation looked only in the zenith direction. Thus, it did not detect cloud radiation unless the clouds were within its 3° field-of-view directly overhead.

Figure 8 shows the efficiency, Q/R_I, for several radiators plotted against normalized temperature depression, $(T_a - T_s)/R_I$. Focus first on the right side where positive values show radiator surface temperatures are below air temperatures. The ideal selective radiator is predicted to achieve temperature depressions that are twice as great as the actual physical black or Tedlar-aluminum radiators with polyethylene covers. For example, at $Q = 0$ with a typical R_I of 90 W/m^2, an ideal radiator is predicted to cool 24C below air temperature. Obviously, the use of a polyethylene cover that is only 80 percent transparent and the higher conduction-convection coefficient measured in actual radiators seriously degrade performance below ideal. Also shown in Figure 8 is a predicted curve for a "white" paint that has an emittance outside the atmospheric window of 0.05. It is predicted to perform about 50 percent better than black paint (or actual white paint) that has an out-of-window emittance of 0.95, but even its performance is far less than ideal because of the cover and higher U factor. The aluminum surface, which was included only for comparison purposes, is predicted to cool only slightly below air temperature. Similarly, the black paint radiator with no cover is predicted to cool only about half as much as the black paint radiator with a cover.

When Q = 0, there are rather significant differences among the radiators, but in practice, external heat would be applied, and the radiators would operate at some other point on their curves (Figure 8). Slightly below air temperature at $(T_a - T_s)/R_I = 0.02$ all of the physical radiators (except aluminum) are predicted to operate with an efficiency, Q/R_I, of 0.6 which corresponds to a radiating power of 54 W/m^2 at a typical R_I of 90 W/m^2. Thus, in this range there is little difference among practical construction materials, which is in accord with the results of Michell and Biggs (1979) who found little difference between white paint and Tedlar-aluminum for cooling two small huts. When the radiator surface temperature is warmer than air temperature [$(T_a - T_s)/R_I$ is negative], the black radiator with no cover is predicted to be much more efficient, as expected.

Also shown in Figure 8 are two dashed curves which bracket the black paint curve. These dashed curves were computed using the black paint radiator properties (Table 1), but with rather extreme air temperature and vapor pressure combinations of 0C - 0.1 kPa and 50C, 4 kPa. These dashed curves give an idea of how much to expect these performance curves to shift with changing environmental conditions. Obviously, these extreme combinations caused a significant shift in the predicted performance curve, but in comparison to the differences between the other curves, the shifts are probably not very important. Thus, these curves can be used for design purposes except for extreme conditions. Furthermore, as will be shown in Figures 9-12, the day-to-day scatter in observed performance for similar days was as large as the predicted shift in the curve for extreme conditions.

Figures 9, 10, 11, and 12 show the efficiency, Q/R_I, versus the normalized temperature depression, $(T_a - T_s)/R_I$, for the aluminum, white paint, black paint-covered, and black paint-uncovered night sky radiators, respectively. The data points are all observed values calculated from the measured 8-14 μ sky radiation, heating rate and air and surface temperatures. All the temperature depression points for Q = 0 from Figures 3, 4, 5, and 6 were normalized by dividing by R_I, and they fall in a pile on top of each other at the bottom of the regression lines in Figures 9-12. Also plotted in the figures are the predicted performance curves computed using the properties from Table 1 in Equation 11 for an air temperature of 20C and a vapor pressure of 1 kPa. The sky radiation was predicted using Equation 4 from Idso (1981a, 1981b), which is for clear skies.

The aluminum and the white paint radiators performed about 20 percent better than predicted, as evidenced by the data points and their regression line being above the predicted curve. Agreement with the black-covered data is somewhat better with only about a 10 percent underprediction. The predicted curve for the black-uncovered radiator is above the regression line, but agreement is good as it falls within the scatter of the data.

Also note that observed performance and closeness to prediction were about the same for both cloudy and clear skies. This result was somewhat surprising because the infrared thermometer viewed only 3° in the zenith direction, whereas the radiators viewed the hemispherical sky. However, radiation from clouds near the horizon must traverse much longer path lengths than those from clouds overhead, and the radiation coming from overhead was measured, so some compensation for cloud effects was obtained.

The scatter in Figures 8-11 is larger than desired, and a closer fit of predicted to observed would also be nice. However, the fit is sufficiently good that one could certainly use Equation 11 and the curves in Figures 7-11 for design purposes. Comparing the spread of the points in Figures 3-6 with those in Figures 9-12, it is obvious that normalization of the temperature depression and of the radiating power with respect to the power of an ideal radiator results in a dramatic compression of the data. Almost all of the day-to-day variability due to the environment is removed, thus permitting comparisons to be made between curves that depend more exclusively on radiator properties. The theory and data presented here demonstrate that the performance of night sky radiators can be predicted rather well. However, their worth as practical cooling devices is rather application and climate dependent, but some examples may serve as a guide. Figure 13 illustrates the optimum clear sky performance to be expected for Phoenix, Arizona, conditions by various radiators for various operating temperatures. The procedure used to obtain these graphs can be used to predict the performance for other climate locations and other operating temperatures. First, average monthly midnight air temperatures, T_a, vapor pressures, e_a, and night lengths, L, were obtained from Schmidli et al. (1971). Midnight temperatures were taken as representative of the average night temperature. Using the air temperatures and vapor pressures, the ideal radiator power, R_I, was calculated from Equation 14 (Figure 2). Then values of $(T_a - T_s)/R_I$ were calculated for the specified operating temperature, T_s. From the $(T_a - T_s)/R_I$ values, the efficiencies, Q/R_I, for the specified types of radiator were obtained from Figure 8. The efficiencies were multiplied by the ideal power, R_I, and the length of night, L, to obtain the nightly total amount of energy lost per unit area.

For Phoenix conditions, vapor pressures are rather low most of the year until July, August, and September when "monsoon" weather patterns bring humid air from the Gulf of California and Mexico (Figure 13a). Concurrent high night air temperatures degrade the efficiency of night sky radiators at the same time as the solar load, S, is relatively large and the length of night, L, to operate is relatively short.

For an operating temperature of 30C (Figure 13b), which is always above the average night air temperature, the radiators perform rather well throughout the year. As expected, the uncovered black radiators had the greatest losses, which even exceeded the solar gain in winter. However, in July the loss from the uncovered radiator reached a minimum of about $4 MJ/m^2$, which is only about 1/7 of the daily solar gain. An application which would absorb and store most of the solar energy such as a closed solar greenhouse would require more than 7 times as much radiator area as solar absorption (greenhouse) area. If, however, the solar receiving area were reflective and insulated during the day so that less than 4 MJ/m^2 is absorbed, then night sky radiators would be an appropriate cooling device.

A temperature of 30C is rather warm, however, with respect to residential cooling applications, for which 25C might be considered a maximum. If the living space were at 27, only a 2C gradient would be available for transporting heat from the living space to the radiator. Referring to Figure 13c, all of the physical radiators perform about equally well in the summer, but as to be expected, the uncovered radiator was superior during the rest of the year when radiator temperature was above air temperature. The minimum nightly loss is about 1.5 MJ/m^2 which is about 1/20 of the solar gain. Thus, if the structure is sufficiently reflective and insulated during the day, it is possible to cool the space at night with equivalent radiator and solar absorption areas.

As mentioned above, 25C is probably a maximum possible for residential applications, but 20C is probably more realistic in order to have a practical gradient between the living space and the radiator surface. The results for 20C in Figure 13d show that an uncovered radiator would not lose energy during July, August, and September, whereas the covered black paint and Tedlar-aluminum radiations could lose about 0.2 and 0.7 MJ/m^2 respectively, which is less than the 2 MJ/m^2 potential of an ideal selective radiator and less than 3 percent of the solar load. These computations presented in Figures 13c and d are consistent with the experience reported by Hay and Yellott (1969) who found that reflective insulation to reduce solar load, coupled with an uncovered night sky radiator surface, produced satisfactory cooling and a comfortable living space in fall and spring in Phoenix. During July through September, however, additional evaporative and electrical cooling were required.

Figure 13e shows the predicted performance for a 10C application, such as storing vegetables. None of the physical radiators could be used for this application during the summer, although they do offer the possibility of losing 1 MJ/m^2 or more for about half of the year.

The results of the computations presented in Figure 13 apply to Phoenix clear sky conditions with average temperatures and vapor pressures. Fluctuations in temperature and vapor pressure above average would degrade the performance, as could the presence of clouds. Generally they show that night sky radiators lack sufficient power to be very practical in Phoenix during July and August. At other times of the year, they offer a possibility for effective cooling without consumption of water or fossil energy. The suitability for other operating temperatures, other radiator properties, and other climates can be determined following the theory presented. They are likely to be attractive for all locations with night temperatures slightly cooler than those in Phoenix in August.

NOMENCLATURE

C fraction of sky covered by clouds

L length of night (sec or hr)

N nightly total energy lost from night sky radiator (MJ/m^2)

Q rate of energy addition to radiator from external source (W/m^2)

R thermal radiation (W/m^2)

S daily total solar energy received (MJ/m^2)

T temperature (K)

$\overline{T}$ average between surface and air temperatures $[(T_m + T_a)/2]$

U overall conduction and convection heat transfer coefficient governing the rate at which energy is transmitted through the insulating air layer ($Wm^{-2}K^{-1}$)

Y shortening variable defined by Equation 10

e vapor pressure (kPa)

f fraction of black body radiation

β transmittance-emittance-reflectance factors defined in Equation 1

δ derivative with respect to temperature

ε emittance

ρ reflectance

σ Stefan-Boltzmann constant ($Wm^{-2}K^{-4}$)

τ transmittance

ϕ relative humidity (%)

Subscripts

C cloudy

I ideal

a air or sky

c cover

o outside 8-14 μ atmospheric window

s radiating surface

w within 8-14 μ atmospheric window

z zenith

Superscripts

o old or from a previous guess or iteration

II. LOW-TEMPERATURE CALIBRATION OF INFRARED THERMOMETERS

Infrared thermometers are useful devices for measuring the temperature of various surfaces. However, they can also be useful for measuring the flux of thermal radiation from the sky, as demonstrated by Idso (1981). The latter task may become increasingly important as efforts are made to evaluate and utilize devices that radiate to the night sky to produce cooling or refrigeration with little consumption of fossil energy or water (Kimball, 1983). Sky radiation, particularly in the 8-14 µm window, will also need to be monitored to aid in evaluation of the effects of the increasing atmospheric CO_2 concentration on climate.

For temperatures in the agronomic range from about -20 to +70C, calibration of infrared thermometers can be accomplished using commercial extended area blackbody sources (Advanced Kinetics Model EABB-250, for example, or simple blackbody cavities e.g., Sadler and van Bavel, 1982). However, to calibrate in the "sky temperature" range from -70 to 0C, some modifications of technique are required. We shall describe a relatively simple adaptation of the blackbody cavity method to the sky temperature range.

Figure 14 is a scale drawing of the calibration apparatus. It basically consists of a blackbody cavity in a dry ice-ethanol bath. It was constructed as follows. The cavity was made from a stainless steel kettle with a wide lid. A hole about 1 cm wider than the body of the infrared thermometer was cut in the center of the lid, and a sheet metal funnel was welded to the top of the lid as shown in Figure 1. Three thermocouples were cemented to the bottom of the kettle (auto/marine silicone sealant), and the inside was painted black. Then the lid was cemented to the kettle body.

The bath vessel was a polystyrene shipping container with a polyethylene film liner added to give added insurance against leaks. The kettle was positioned in the middle of the polystyrene container. It rested on four metal blocks near its outer edge which lifted the kettle 2.5 cm off the bottom of the polystyrene container. The bath was then filled with ethanol to about 2 cm above the top of the kettle, about 40 ℓ.

A warning must be stated here. Ethanol is flammable, so care must be taken to avoid ignition sources. When the ethanol is warm, electrical machinery should be off. Smoking should not be allowed, of course. When not in use, the bath should be tightly covered.

The bath is now ready to start a calibration run. Dry ice is slowly added to cool the ethanol. Adding the first pieces is the most dangerous because they will cause the ethanol to "boil" most vigorously. If too much is added at once, the ethanol will boil over the top and spill. The high vapor pressure at the start adds to the fire danger. About 1/2 kg pieces are a good size to use at first, and larger can be added later. About 15 kg total of dry ice are needed.

After the bath temperature has reached its minimum, near -70C, the infrared thermometer (Everest Interscience Model 112) is mounted to view the bottom of the kettle in the middle of the neck of the funnel as shown in Figure 1. A vinyl tube carrying a stream of dry N_2 gas with a flow rate of about 50 ml/min is inserted into the space between the thermometer and the wall of the neck of the funnel. The dry N_2 prevents or at least minimizes condensation of water vapor on the inside walls of the kettle. The rest of the gap between the thermometer and the funnel neck is filled with polystyrene insulation to reduce the thermal contact between the body of the thermometer and the rest of the apparatus. The insulation is not packed tightly enough to restrict the flow of N_2, however. A fan was mounted about 30 cm from the infrared thermometer to blow ambient air directly on the thermometer body. The fan plus the insulation in the neck served to keep the thermometer itself close to ambient temperature. In some early runs with no fan and no insulation, the temperature of the thermometer itself became steadily cooler than ambient, and this cooling affected the calibration.

After the thermometer and fan are mounted, the actual calibration can start. The bath will slowly warm for several hours, and the cavity temperature and infrared thermometer output can be recorded every 10 minutes or other convenient interval. After the bath stops boiling from evolution of CO_2, it can become rather stagnant, and temperatures near the top of the cavity can become 20C warmer than at the bottom. Therefore, a tube with a weight on the end is lowered into the bath, and air is bubbled into the bottom of the bath at about 50 ml/min. The bubbling stirs the bath and keeps all sides of the cavity to within a few degrees. Most of the sensed radiation originates from the bottom of the cavity where the temperature is measured, so temperature differences of a few degrees can be tolerated. Finally, while a run is in progress, aluminum foil is used to cover the bath between the funnel and the edge of the polystyrene container. The foil slows the evaporation of ethanol.

Sadler and van Bavel (1982) discussed possible sources of error in their apparatus, and most of their comments apply here. First, of course, the calibration of the infrared thermometer can be no better than the calibration of the temperature sensors used and associated read-out instrumentation. We calibrated our copper-constantan thermocouples against a mercury-in-glass thermometer dipped into the cold bath while it was bubbling fairly vigorously from CO_2 evolution. The four thermocouples agreed to within 1C. Like van Bavel and Sadler, we fastened the sensors to the inside of the cavity and then blackened the cavity to try to get temperatures as representative as possible of the cavity surface. The average of the temperatures from the three bottom thermocouples was used. As already mentioned, the infrared thermometer viewed the bottom surface where the thermocouples were installed, and we also bubbled air into the bath to prevent stagnation and minimize temperature gradients within the apparatus. The emittance of the paint used was estimated to be at least 0.95, so the cavity emittance should be greater than 0.99, based on a spherical cavity chart (Sparrow and Hess, 1966).

The primary source of error which concerned us in this low temperature calibration was formation of fog in the chamber and warming of the cavity surface from condensation. Before dry N_2 gas was injected into the cavity, copious amounts of frost formed inside the apparatus, and sometimes fog was seen. The fog droplets would not be in thermal contact with the bath and could introduce a gross error. If the rate of condensation on the surface were too high and the frost layer became thick and insulative, then the thermocouples would not sense the true surface temperature. The frost should not affect the cavity emittance because the frost itself has a thermal emittance of at least 0.82 (Sellers, 1965) which should still yield a cavity emittance of at least 0.98 (spherical cavity chart, Sparrow and Hess, 1966). However, continuous bleeding of dry N_2 gas from a high pressure cylinder eliminated the fog problem and greatly reduced frost formation to the extent that the bottom of the cavity appeared more dry than wet or frosty at the end of a run.

Another source of error with our infrared thermometer was that the calibration curve shifted somewhat with the body temperature of the thermometer itself. Therefore, we found it necessary to make several calibration runs over a range of ambient temperatures so that in actual use an appropriate correction could be made to the sky temperature readings to adjust for different ambient temperatures. As discussed previously, the fan and the insulation around the neck were used to keep the infrared thermometer close to the ambient temperature of a particular calibration run.

SUMMARY AND CONCLUSIONS

The feasibility of conducting a large CO_2-enrichment experiment to determine the effects of the increasing atmospheric CO_2 concentration on productivity, water use, and photosynthesis of crop plants under normal and stress levels of water and nitrogen was evaluated. The experiment as originally planned required 36 open-top enrichment chambers and about 600 Mg/year of CO_2. This amount of pure CO_2 was prohibitively expensive from commercial sources, so much effort was expended toward finding inexpensive alternative sources of CO_2. The only possible source of inexpensive, pure CO_2 (an ammonia plant) closed because of natural gas pricing. Numerous contacts were made to find sources of relatively clean combustion gas, and two sites were located which also had suitable land available nearby to run the experiment. However, analyses of the combustion gases from the exhaust stacks showed levels of ethylene and other contaminants that were high enough to require removal before such an experiment could be conducted with confidence. Therefore, an experiment of reduced scale and number of treatments with only 6 chambers is planned for the coming year, and as time permits, an effort will be made to test ways to clean combustion gases so that a full scale experiment can be conducted in the future.

The user's manual for the Modular Energy Balance (MEB) model of greenhouses and other latent heat devices was completed except for typing the last section. The manual is to be published by ARS in the AAT series, but preprint copies will be made available to serious users. The model itself was adapted from a Data General to a Hewlett Packard computer and in the process made much less specific to computer brand. A set of eight standard examples which utilize all 24 sub-device models was developed as a debugging aid and an educational tool for new users. Additional comparisons were made with measurements from prior years reconfirming the accuracy of the complicated greenhouse model.

A theoretical equation was derived to predict the surface temperature of night sky radiators as a function of power, Q, from radiator properties and sky conditions. The power of an ideal radiator, R_I, which is pefectly black in the 8-14 μ atmospheric window, perfectly reflective outside the window, and has a transparent cover, was used to define radiator efficiency as Q/R_I. Plots of Q/R_I against $(T_a - T_s)/R_I$ were primarily dependent on radiator properties and only slightly on environmental conditions. These curves provide a means to compare different radiators and to aid in the design and prediction of performance of night sky radiators.

Performance measurements were obtained with three night sky radiators constructed with surfaces of aluminum, white TiO_2 paint, and black paint, all three covered with polyethylene. Similar measurements were also obtained with a fourth radiator that had an uncovered black paint surface. Depressions below air temperature for Q = 0 of 6 and 2.5C were observed with the aluminum and the black-uncovered radiators at vapor pressures of 0.5 and 2 kPa, respectively. Depressions of the white and black paint covered radiators were about 11 and 6C at vapor pressure of 0.5 and 2 kPa. Fair agreement with theory was achieved. Calculation of cooling loss from various radiators for Phoenix, Arizona, climate was made. Generally the losses were too small for practical use in July and August, but had potential for other months. The procedure presented can be used to predict the feasibility of radiator use for other application temperatures, climates, and radiator properties.

A method was developed for calibrating infrared thermometers over a temperature range from -70 to OC. Once calibrated for this range, the thermometer can then be used to measure the flux of thermal radiation from the sky. Salient features of the method included using dry ice in ethanol to cool a blackbody cavity, using dry nitrogen gas to minimize condensation and using a fan plus insulation to keep the temperature of the infrared thermometer close to ambient.

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<u>PERSONNEL:</u> B. A. Kimball and S. T. Mitchell

Table 1. Radiative properties of night sky radiators used to compute theoretical curves from Equation 11.

Parameter	Ideal: Selec.	Ideal: Black	Alum.	"White" Paint	Black Paint: Cover	Black Paint: No Cover	Tedlar on Alum.4/
ε_{sw} 8-14 μ window surface emittance	1	1	0.14 1/	0.92 2/	0.95 3/	0.95 3/	0.85
ε_{so} outside window surface emittance	0	1	0.14 1/	0.05 2/	0.95 3/	0.94 3/	0.15
τ_{cw} 8-14 μ cover transmittance	1	1	0.80 4/	0.80 4/	0.80 4/	1	0.80
τ_{co} outside cover transmittance	1	1	0.80 4/	0.80 4/	0.80 4/	1	0.80
ε_{co} 8-14 μ cover emittance	0	0	0.10 4/	0.10 4/	0.10 4/	0	0.10
ε_{co} outside cover emittance	0	0	0.10 4/	0.10 4/	0.10 4/	0	0.10
U convection-conduction heat transfer coefficient ($Wm^{-2}C^{-1}$)	1.5 5/	1.5 5/	2.7 6/	2.7 6/	2.7 6/	9.5 7/	3.0

1/ From Duffie and Beckman (8).
2/ From Harrison and Walton (11).
3/ Estimated to be between Parsons black and white from Duffie and Beckman (8).
4/ From Catalanotti et al. (7). Cover was polyethylene.
5/ From ASHRAE (1) for the coinductance of a stagnant, 19-mm-thick, low emittance air space with downward heat flow. The low emittance value was taken because it should contain only conduction-convection effects and not radiation.
6/ Measured.
7/ I[illegible] th[illegible] Ada[illegible] expr[illegible]on, [illegible] = 5[illegible] 3.[illegible] (m/[illegible] for[illegible] m/[illegible] ind[illegible].

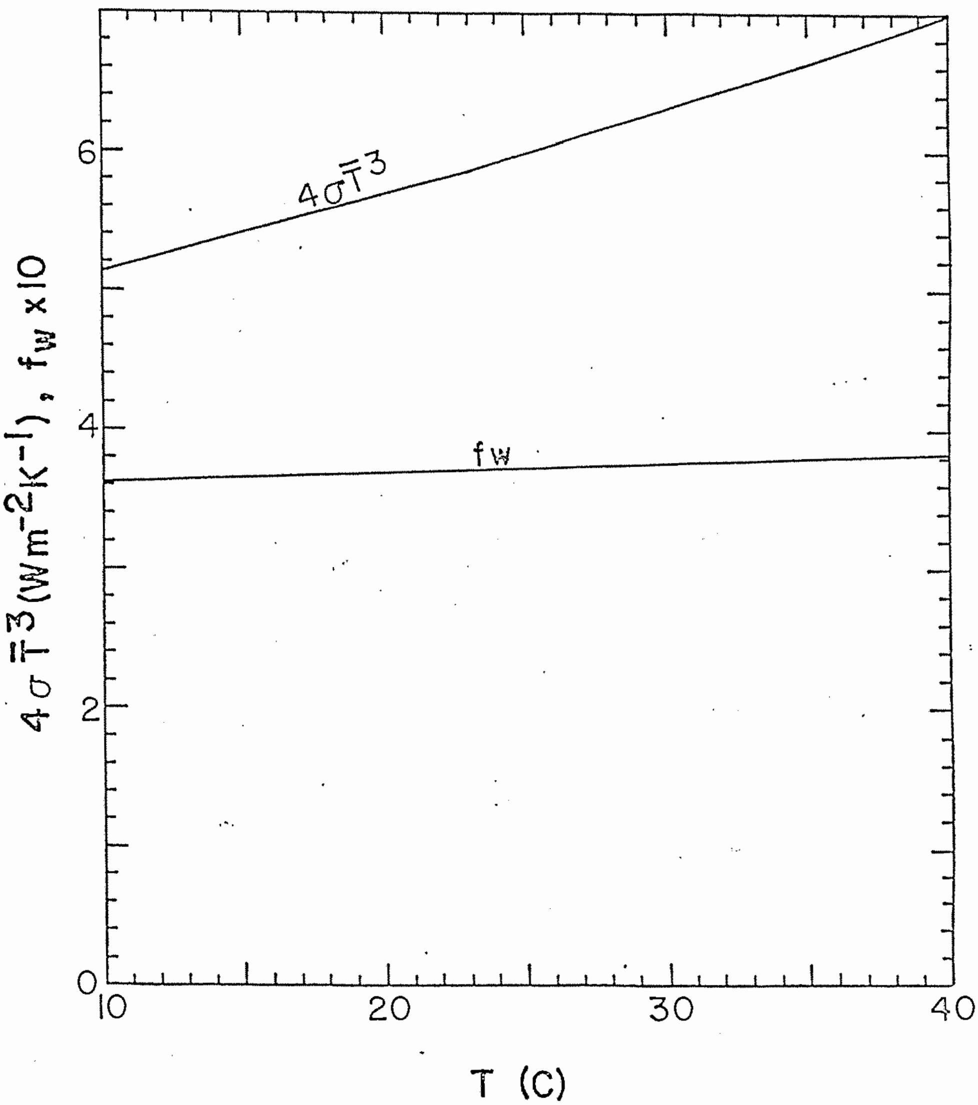

Fig. 1. Plot of the quantity $4\sigma\bar{T}^3$ where $\bar{T}$ is in °K against temperature. Also the fraction of black body radiation emitted in the 8-14 μm band, f_w, against temperature. (Harrison 1960, Table 2).

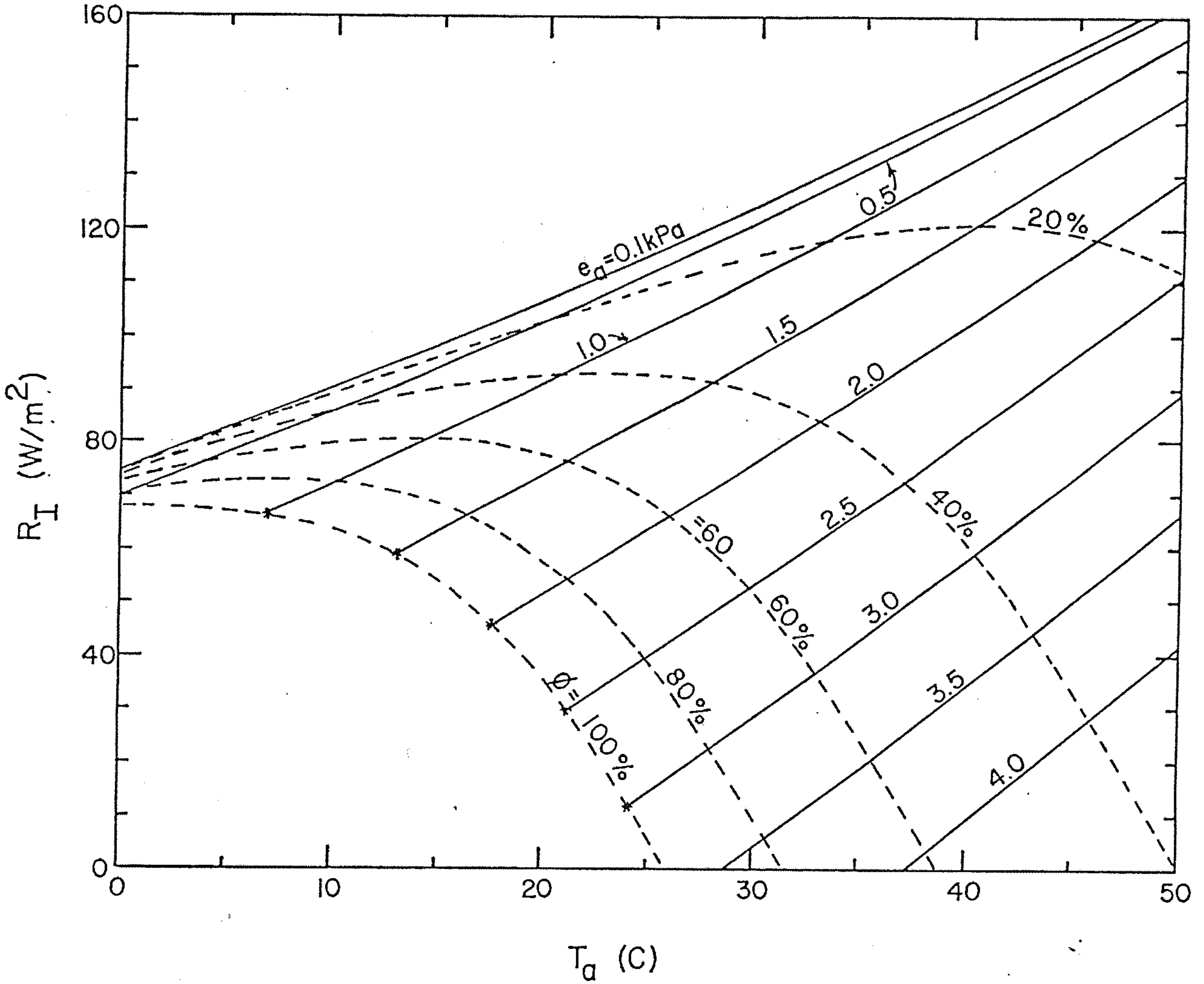

Fig. 2. Power, R_I, at which the atmosphere can receive radiation from an ideal selective radiator at air temperature, T_a, for various vapor pressures, e_a, and relative humidities, ϕ.

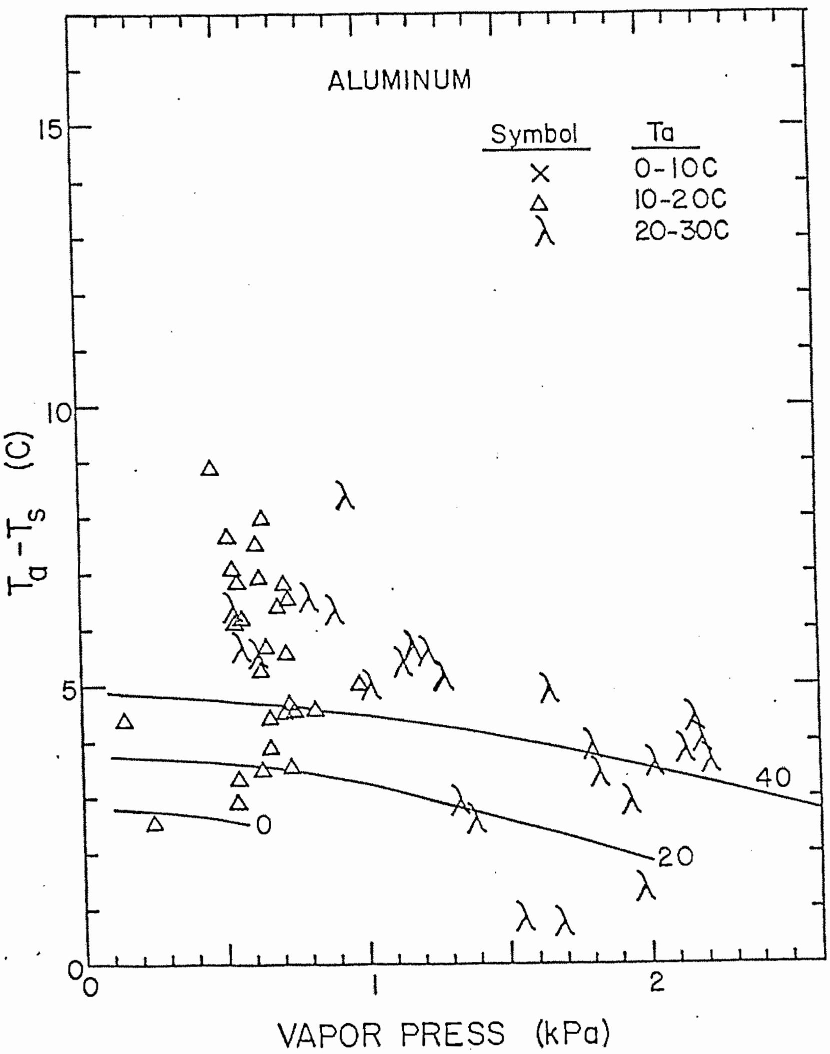

Fig. 3. Depression of the surface temperature of the aluminum night sky radiator below air temperature versus air vapor pressure for times when the sky was clear and no external energy was applied (Q = 0). The solid theoretical curves were computed using Equation 11 with parameters from Table 1 for air temperatures of 0, 20, and 40 C.

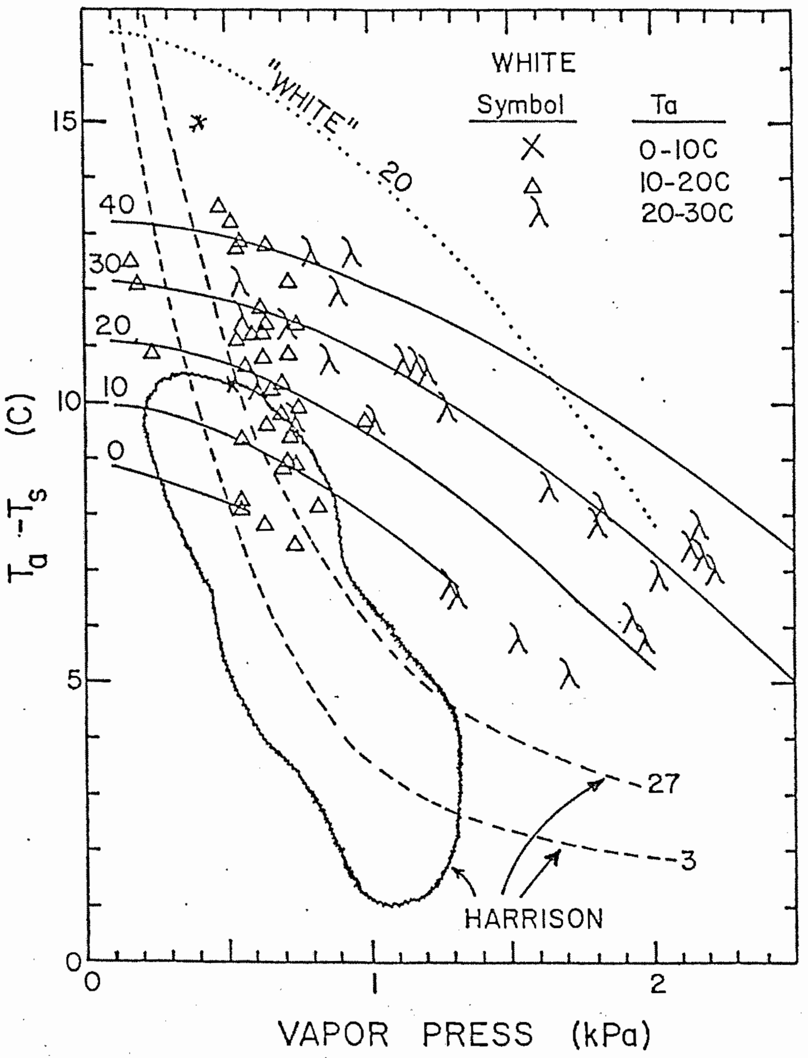

Fig. 4. Depression of the surface temperature of the white TiO_2 night sky radiator below air temperature versus air vapor pressure for times when the sky was clear and no external energy was applied (Q = 0). The solid theoretical curves were computed using Equation 11 with black paint parameters from Table 1 for air temperatures of 0, 10, 20, 30, and 40 C. The "white" dotted curve was computed similarly using the "white" paint properties of Harrison and Walton (1978) listed in Table 1 for an air temperature of 20 C. The data point marked with an * is from Harrison and Walton. The dashed theoretical curves are from Harrison (1981) for an air temperature of 27 and -3 C and the thin wavy line brackets the measured data of Harrison.

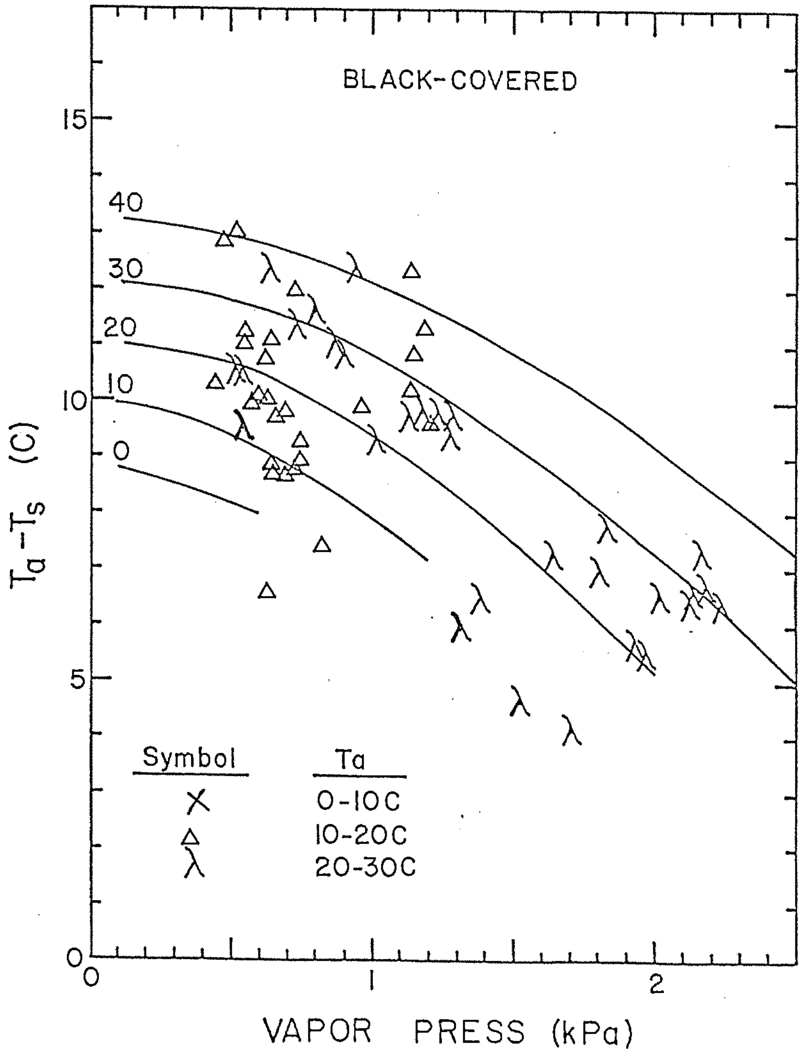

Fig. 5. Depression of the surface temperature of the black covered night sky radiator below air temperature versus air vapor pressure for times when the sky was clear and no external energy was applied (Q = 0). The solid theoretical curves were computed using Equation 11 with parameters from Table 1 for air temperatures of 0, 10, 20, 30, and 40 C.

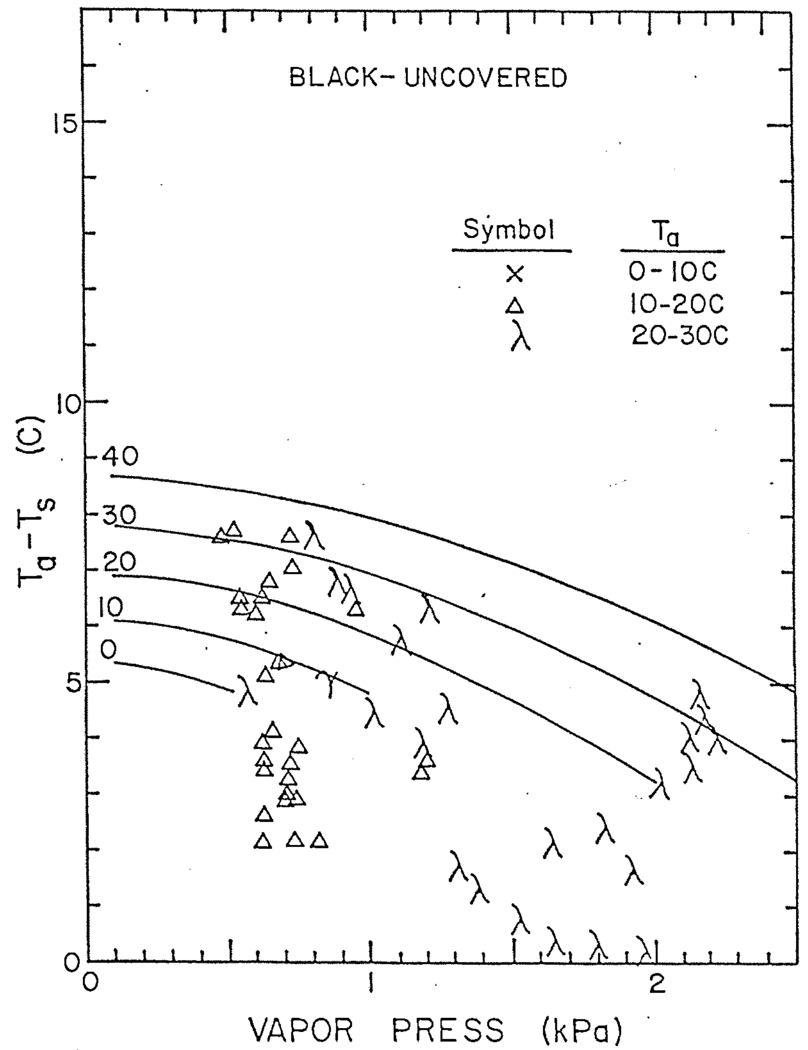

Fig. 6. Depression of the surface temperature of the black uncovered night sky radiator below air temperature versus air vapor pressure for times when the sky was clear and no external energy was applied (Q = 0). The solid theoretical curves were computed using Equation 11 with parameters from Table 1 for air temperatures of 0, 10, 20, 30, and 40 C.

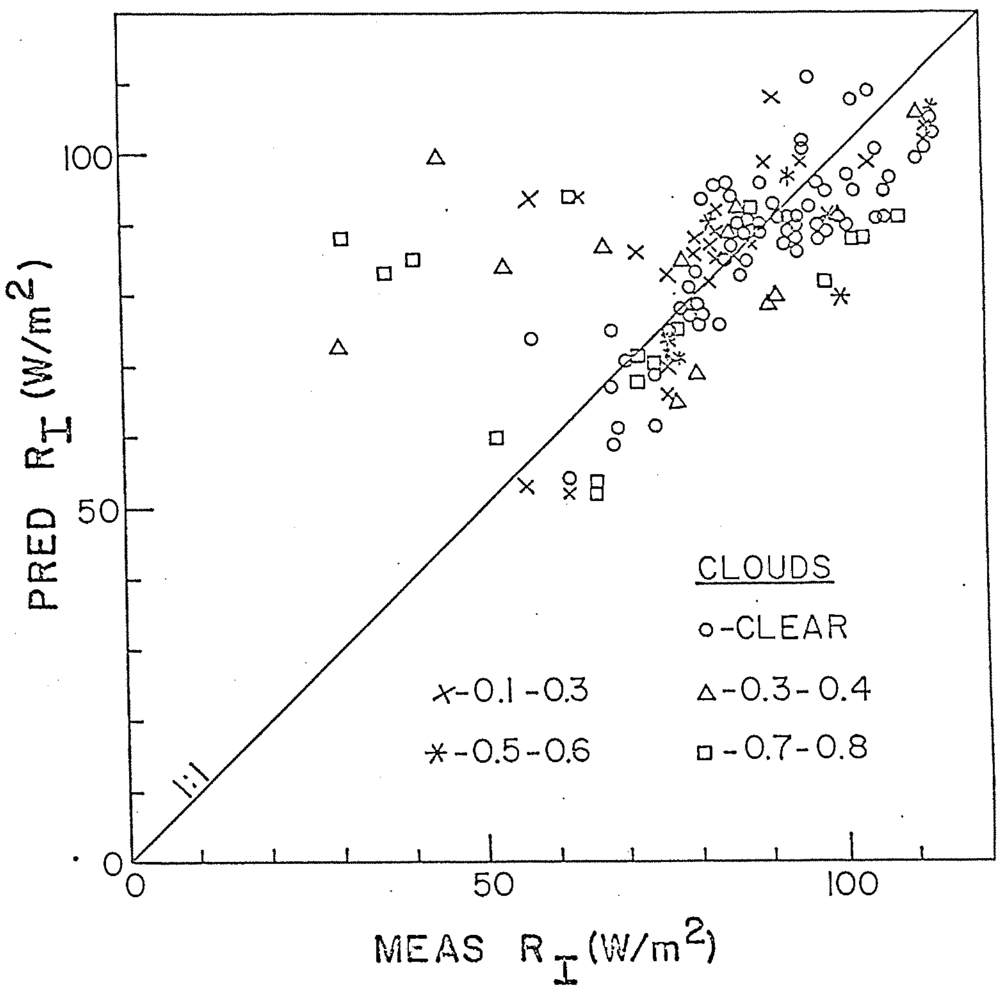

Fig. 7. Predicted versus measured values of the power of an ideal radiator operating at air temperature for various fractions of cloud cover.

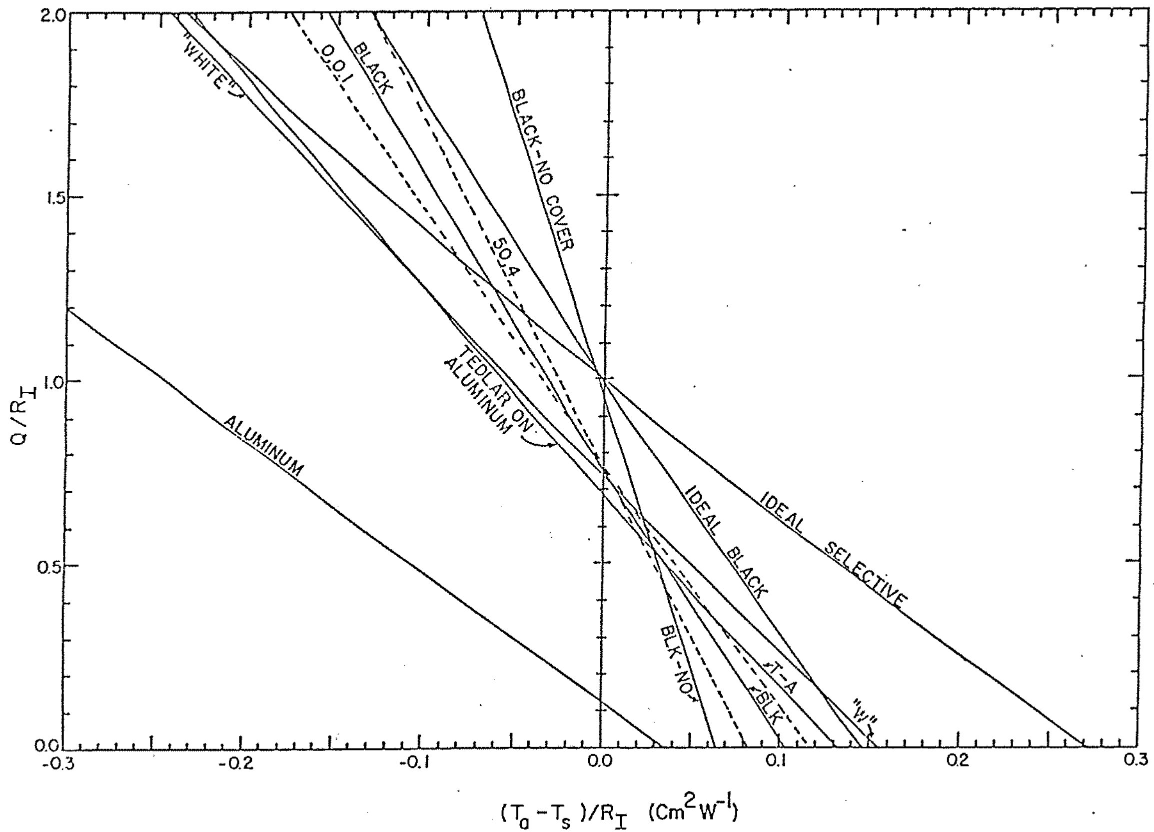

Fig. 8. Night sky radiator efficiency, Q/R_I, versus the normalized depression of surface temperature, T_s, below air temperature, T_a, for various radiators whose properties are listed in Table 1. The solid curves were computed from Equation 11 for an air temperature of 20 C and a vapor pressure, e_a, of 1.0 kPa. The dashed lines bracketing the solid black paint curve were computed from Equation 11 for black paint using T_a = 50 C, e_a = 4 kPa and T_a = 0 C, e_a = 0.1 kPa.

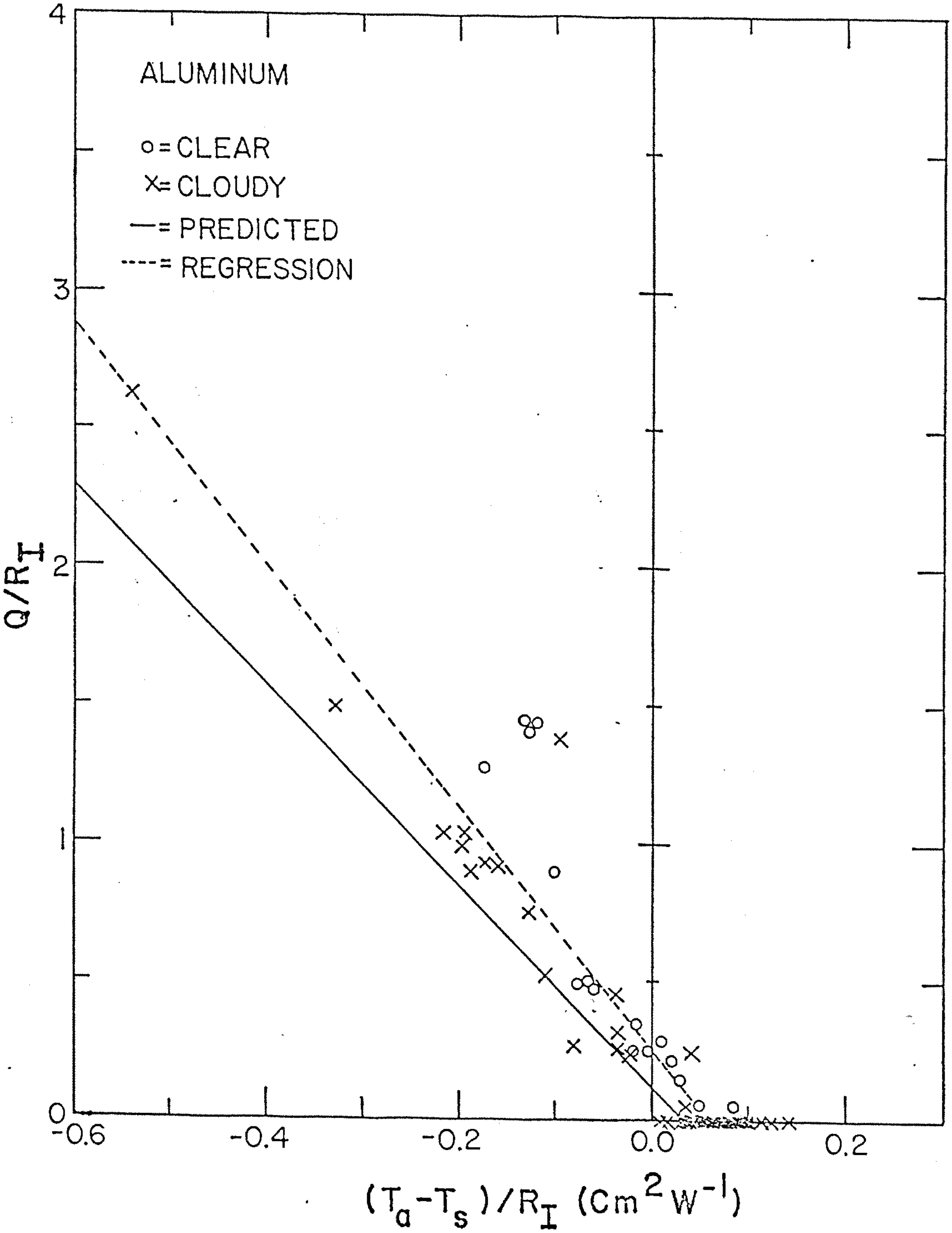

Fig. 9. Efficiency, Q/R_I, versus normalized temperature depression, $(T_a - T_s)/R_I$, for a night sky radiator with an aluminum surface and a polyethylene cover.

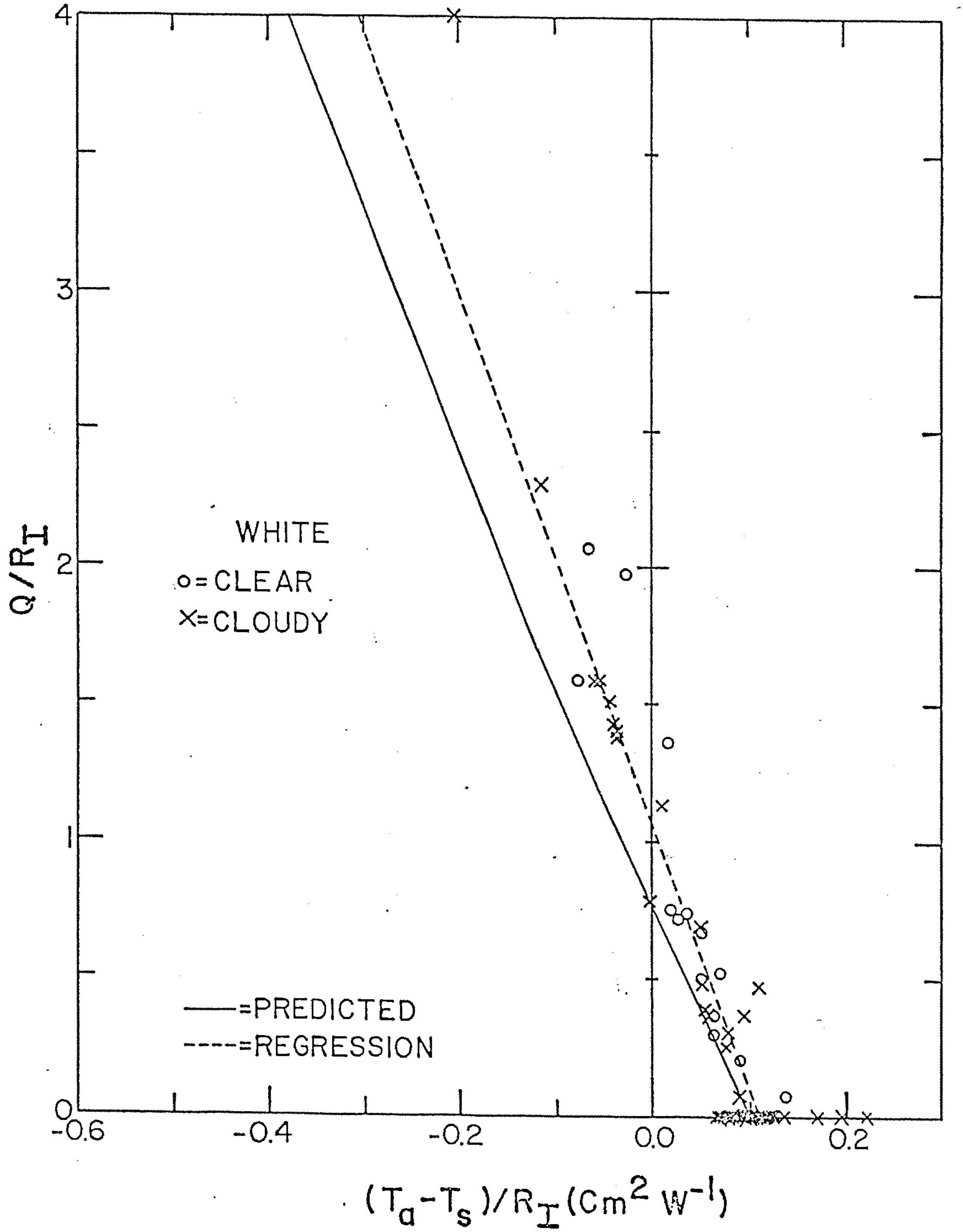

Fig. 10. Efficiency, Q/R_I, versus normalized temperature depression, $(T_a - T_s)/R_I$, for a night sky radiator with a white TiO_2 paint surface and a polyethylene cover.

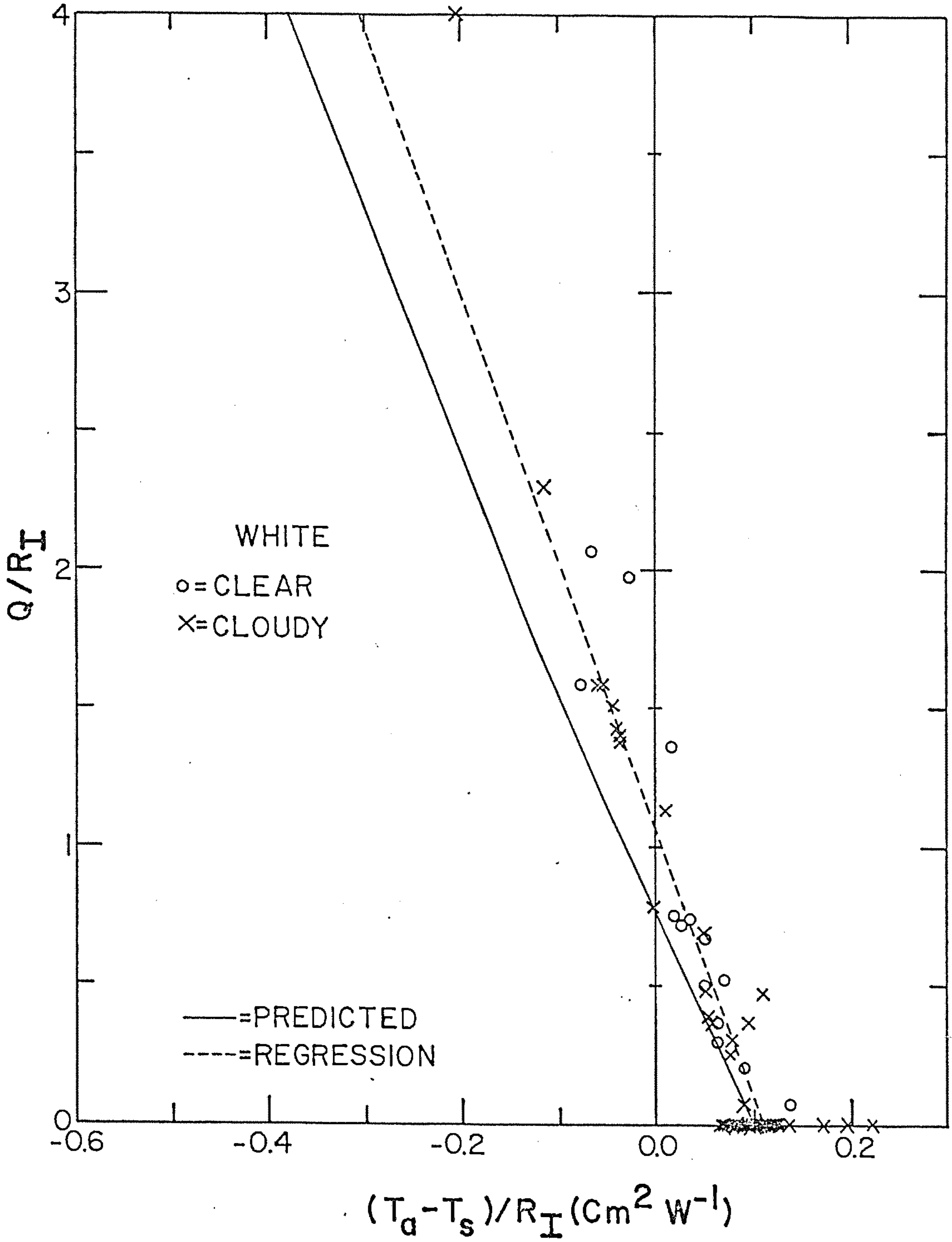

Fig. 11. Efficiency, Q/R_I, versus normalized temperature depression, $(T_a - T_s)/R_I$, for a night sky radiator with a black paint surface and a polyethylene cover.

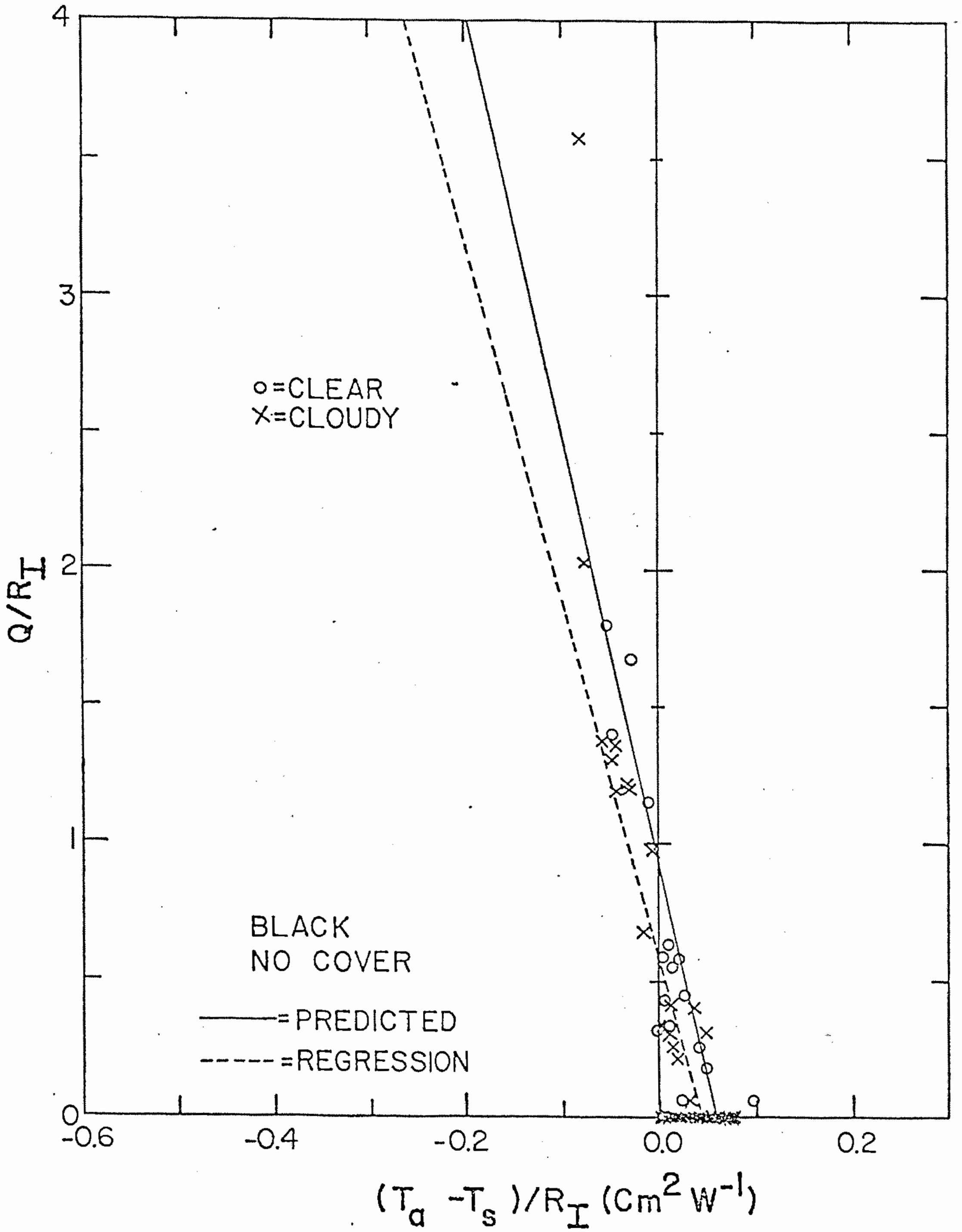

Fig. 12. Efficiency, Q/R_I, versus normalized temperature depression, $(T_a - T_s)/R_I$, for a night sky radiator with a black paint surface and no cover.

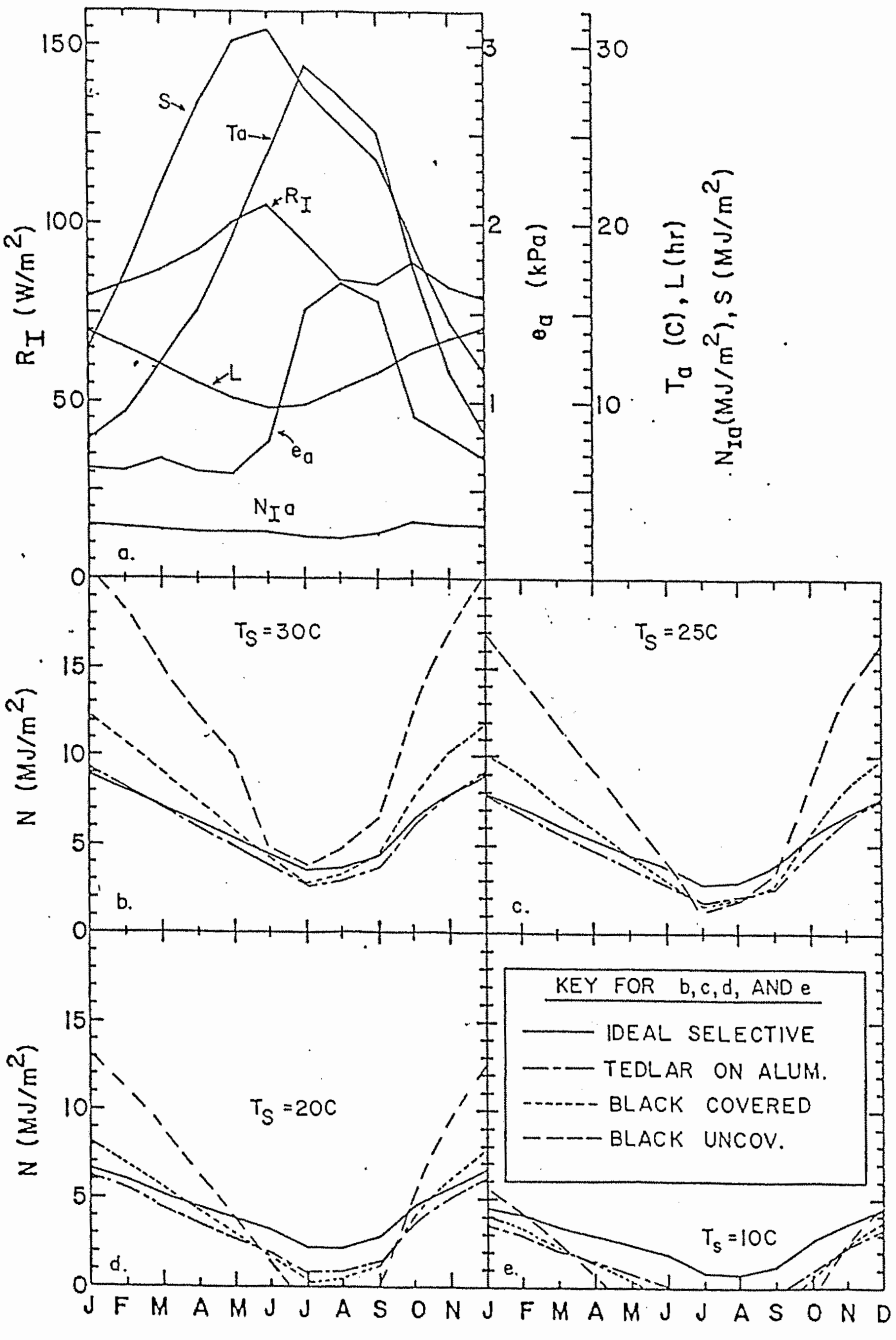

Fig. 13. Total nightly loss of energy, N, from various radiators versus month of the year for Phoenix, Arizona, for operating temperatures, T_s, of 30, 25, 20, and 10 C in b, c, d, and e, respectively. The radiators include ideal selective, Tedlar on aluminum with polyethylene cover, black paint with polyethylene cover, black paint with polyethylene cover, and black paint with no cover with properties listed in Table 1. Also show in a. for Phoenix are the monthly average midnight air temperatures, T_a, and vapor pressure, e_a, night length, L; daily solar radiation, S, and power, R_I, and total nightly loss of energy, N_{Ia}, for an ideal radiator operating at air temperature.

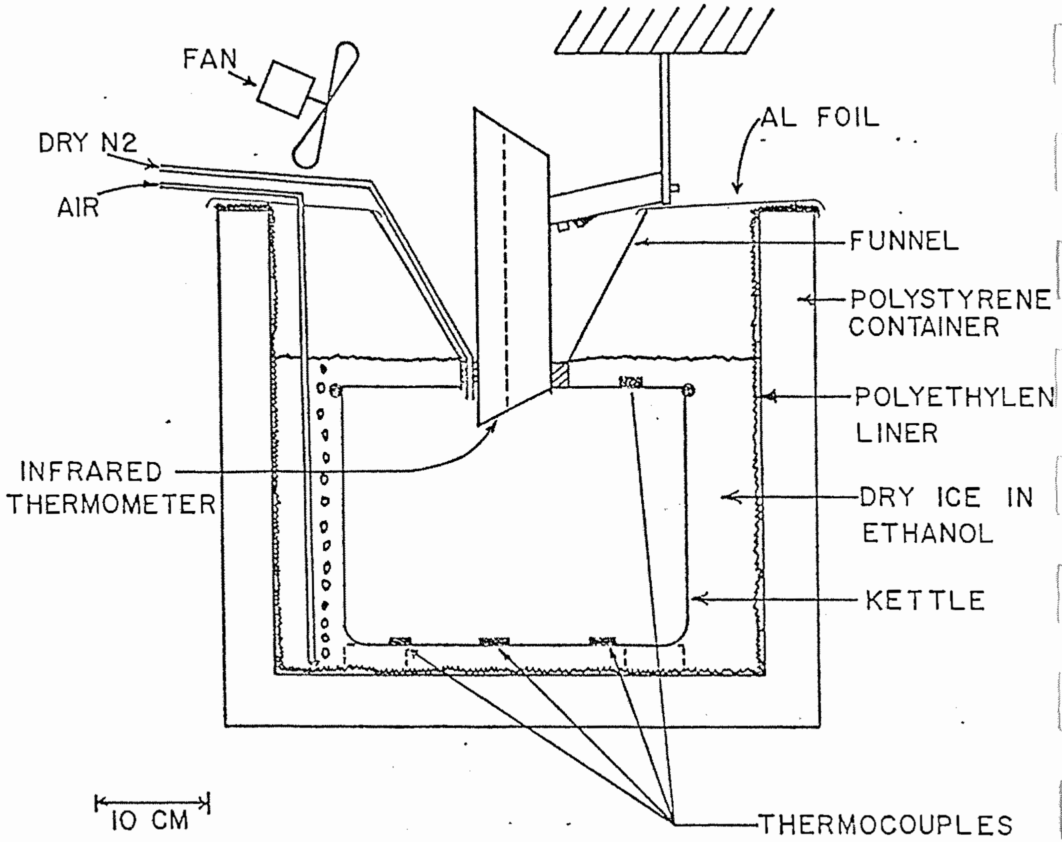

Fig. 14. Scale drawing of the black body cavity cooled by dry ice in ethanol for low temperature calibration of an infrared thermometer.

TITLE: MICROBIOLOGY OF SOIL AND WATER SYSTEMS FOR RENOVATION AND CONSERVATION OF WATER

NRP: 20790 CRIS WORK UNIT: 5510-20790-002

The Subsurface Water Management Group has completed its work on renovation of sewage effluent by groundwater recharge with rapid-infiltration basins. Therefore, this CRIS Work Unit was terminated and a final report was submitted on 1 September 1982. In July 1982, the microbiologist on this project, R. G. Gilbert, transferred to Prosser, Washington. Papers are now being prepared for various journals to finish the work. Significant results of this work on biological nitrogen transformations in soil systems used for wastewater renovation are summarized as follows:

1. Environmental conditions for nitrification-denitrification reactions responsible for N-removal occurred mainly during the first 48 to 72 hours of drying.

2. Nitrite-N and/or nitrate-N production by nitrification was the major factor limiting the denitrification potential and N-removal.

3. Wastewater effluents treated with chemicals for odor control that inhibit nitrification should not be used for land treatment systems designed and managed for maximum N removal by denitrification.

4. Nitrification rates in the summer were about twice those during the winter.

5. Denitrification rates were greatest during the first two to three days of drying regardless of the season of the year.

6. Nitrification-denitrification reactions were similar in soil basins intermittently flooded with either chlorinated or non-chlorinated wastewater.

7. Hydrogen sulfide present in wastewater or evolving from the land treatment system may reduce nitrogen removal by inhibiting nitrification-denitrification reactions.

8. The evolution of nitrous oxide from nitrification-denitrification processes in soil intermittently flooded with sewage effluent originated from denitrification of nitrified N and not from the nitrification of ammonium-N.

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

TITLE: WASTEWATER RENOVATION BY SPREADING TREATED SEWAGE FOR GROUNDWATER RECHARGE

NRP: 20790 CRIS WORK UNIT: 5510-20790-003

I. 23rd Avenue Project

The research activities at the 23rd Avenue project, which is a rapid-infiltration project of four 10-acre basins to renovate secondary sewage effluent by groundwater recharge, had come to a halt at 30 June 1980, when the last samples for trace-organics analyses were taken. In the spring of 1982, the final report on the trace organics analyses, which were done at Stanford University, was completed and published. Summaries of the major findings on trace organics were already reported in the 1981 Annual Report of the U. S. Water Conservation Laboratory. A manuscript describing the research activities and results for the entire study period of the 23rd Avenue project (1975-1980) was completed. Future activities at the 23rd Avenue project will primarily consist of showing the field system to visitors, and to assist the City of Phoenix in a plan to enlarge the system to about 120 acres of infiltration basins and about nine wells for pumping the renovated water from the aquifer. This project should be capable of renovating about 35 mgd of secondary sewage effluent, which is about equal to the entire outflow from the treatment plant. The renovated water would be discharged in a canal for conveyance to an outlying irrigation district. This district would then allow the City of Phoenix to pump an equivalent amount of high quality, indigenous groundwater into a canal of another irrigation district, which would then let the City of Phoenix divert the same amount of water from one of its other canals to augment the City's municipal water supply.

II. Column Studies

The studies on downward flow of water in stony vadose zones were continued in the sand and boulder column (see 1981 Annual Report). The water retention curve for the sand-boulder column was further defined by including rewetting and hysteresis. A 10 cm pulse of water was added to the column and allowed to drain. As the wave of water passed through the column, pressure head and water content measurements were taken. The pulse of water became attenuated as it moved down the column. A high water content change was observed near the surface with progressively smaller changes further down. Hysteresis scanning curves at different water contents were then determined from the wetting and draining data observed at each tensiometer depth. The wetting leg of the water retention curve was further defined from water content-pressure head data obtained from the flooding of the column. The results are shown in Figure 1 where the different symbols represent different tensiometers. The dashed line is the curve determined in 1981 from steady state infiltration and drainage. The hysteresis scanning curves can be adequately described from neutron water content data and tensiometer readings.

The column was allowed to drain for an extended period of time after the addition of the 10 cm pulse. Figure 2 shows the total amount of water in the column for the drainage time. The column surface was uncovered after

154 days, and evaporation was allowed. The soil water depletion rate determined from neutron measurements was .002 cm/day at that time. A slight increase in the depletion rate was observed after the cover was removed. After 273 days, the depletion rate was .0037 cm/day. The outflow from the column was .0021 cm/day indicating an evaporation rate of .001 cm/day. The depletion rate can be measured with the neutron probe by taking several measurements. When the depletion rate is very small, the measurements must be taken over a long enough period of time in order to observe a change in water content.

III. Pit Bailing Method

As an ad hoc project, a sand-model study was performed to check the validity of geometry factors, derived from the piezometer and augerhole methods for in-place measurement of soil hydraulic conductivity, in the calculation of soil hydraulic conductivity with the pit bailing method. The pit bailing method consists of digging a pit or round hole into the groundwater with, for example, a backhoe, letting the water level in the pit come to equilibrium, quickly removing a volume of water, and measuring the subsequent rate of rise of the water level in the pit for calculation of the hydraulic conductivity K of the surrounding soil. The pit bailing method was originally developed in the Northeast for septic tank leach field design. However, since it works well in stony soils (unlike the augerhole and piezometer methods), it could also be of value for drainage design and other agricultural applications.

In the original version of the method, the calculation of K from the rise of the water level in the pit was based on the assumption of horizontal flow to a cylindrical hole (Thiem well-flow equation). Since this assumption causes serious errors when the impermeable layer is not close to the bottom of the pit or when the soil below the pit is underlain by permeable material, geometry factors for the piezometer method were extended so that they would apply to the pit bailing method. For this purpose, the pit was considered as a piezometer cavity with the water table essentially at the top of the cavity. The hydraulic conductivity K of the soil is then calculated with the equation developed for the piezometer method. Since the pit could also be considered as a large-diameter augerhole with shallow penetration into the groundwater, the geometry factors of the augerhole were also extended so that they would apply to the short, fat augerhole of the pit bailing method. The augerhole geometry factors were calculated by C. W. Boast of the University of Illinois, using the original computer program developed for the augerhole method. The piezometer- and augerhole-derived geometry factors, however, produced different values of K when applied to the pit bailing method.

To determine which gave the best estimate, a sand model study was set up where K calculated with the pit bailing method and the two geometry factors could be compared with K determined from measurements of flow rate and hydraulic gradient for vertical flow in the sand. For this purpose, the sand was underlain by a layer of gravel so that by flooding the sand with water and using the gravel layer as a drain, K of the entire body of sand could be determined as in a permeameter. In addition, K of the upper sand was determined with seepage meter techniques (like the double-tube method). Based on these measurements, the average value of K of the sand in the box was determined as 37 m/day. The sand tank itself was 239 cm in diameter and the sand layer was 70 cm thick.

To simulate the pit bailing method, pits were dug in the sand with depths ranging from 4 to 20 cm and diameters (2r) from 15 to 60 cm. The water table in the tank was kept at a depth of 3 cm below the sand surface. Thus, the equilibrium water depths L_c in the pits ranged from 1 to 17 cm, and the depth D of the gravel layer below the pit bottom from 50 to 66 cm. The results (Table 1) showed that the geometry factors from the piezometer method (expressed as A_p/r) yielded an average K-value of 30 m/day or 81 percent of the true K of 37 m/day, whereas the geometry factors from the augerhole method (expressed as A_a/r) yielded an average K-value of 17 m/day or only 47 percent of the true K. Thus, the piezometer-derived geometry factors gave much better values of K with the pit bailing method than the augerhole-derived factors. Figure 3 shows that the piezometer-based K-values for the pit in the sand model increased slightly with increasing diameter of the pit. The augerhole-based values seemed to increase somewhat with increasing depth of the pit below the water level.

Hydraulic conductivity components in horizontal and vertical direction can be evaluated with the pit bailing method if K is determined with two pits of different size. A detailed description of this procedure, which involves transformation of the pit system in an anisotropic soil into an equivalent isotropic system, was included in the manuscript on the pit bailing method and the use of piezometer-method derived geometry factors in the calculation of K. The manuscript was completed in the fall of 1982, and submitted for publication in the Transactions of the American Society of Agricultural Engineers.

SUMMARY AND CONCLUSIONS:

23rd Avenue Project

The research activities at the 23rd Avenue Project came to a halt on 30 June 1980, when the last samples of secondary effluent and renovated water were taken for trace organics analyses. These analyses were completed in 1981, and the final report came out in 1982. The final manuscript on the 23rd Avenue work could then be written and it was completed in December 1982. The results indicated that the soil-aquifer filtration treatment obtained at the 23rd Avenue Project produces renovated water that is suitable for unrestricted irrigation and recreation. The 40-acre system has a capacity of about 11 mgd. Expansion of the system to 120 acres could increase the capacity to about 35 mgd, which is about equal to the output of the sewage treatment. The static water table depth is about 50 ft, indicating that the renovated water can be pumped from the aquifer at relatively low cost.

Column Studies

Studies on downward flow of water in stony vadose zones were continued in 1982. The studies were done on a laboratory column 3.35 m long, 1.24 m in diameter, and filled with layers of boulders surrounded by sand. Water contents were measured with the neutron method, and pressure heads with tensiometers. After an extended drainage period, a 10 cm pulse of water was added to the column. The wetting leg of the water retention curve and hysteresis scanning curves were determined from the redistribution of the 10 cm pulse as it moved down the column. The column was allowed to drain for an extended period of time. After 154 days, the depletion rate was 0.002 cm/day. The column was then uncovered and evaporation permitted. After 270 days, the depletion rate was 0.0037 cm/day, and the outflow from the bottom of the column was 0.002/cm/day. Thus, evaporation was calculated to be 0.0016 cm/day, or about 0.05 cm/month. This is a small amount. Since the column was indoors and not subject to temperature changes or wind effects, the "deep" evaporation probably was mainly due to diurnal and other barometric pressure changes.

Pit Bailing Method

The pit bailing method is a technique for in-place measurement of soil hydraulic conductivity below a water table. A hole is dug (normally with backhoe) to below the groundwater table. After equilibration, the water level in the pit is rapidly (instantaneously) lowered and the subsequent rise of the water level is measured for calculation of the hydraulic conductivity K around the pit. The pit bailing technique was originally developed for septic tank leach field design. However, the method is also useful for in-situ measurement of K for other purposes. This is particularly true for stony soils, where augerhole and other methods are difficult and often fail. Another advantage of the pit method is that the volume of soil on which K is determined is larger than for the augerhole and piezometer methods. The equation originally given for the pit method was based on the Thiem formula, which limited the method to situations where the pit bottom was at or close to the impermeable layer. The geometry of the flow system for the pit method, however, is similar to that for the piezometer method if the water table coincides with the top of the piezometer cavity. Thus, the equation for the piezometer method can also be used for the pit method. This extends the applicability of the pit method to partially penetrating pits in soils that are underlain by either impermeable or very (infinitely) permeable material. Geometry factors for the piezometer method presented by Youngs were extrapolated to the case where the static water table coincides with the top of the cavity. The resulting values then can be used for the pit method. The validity of this approach was demonstrated in a large sand tank where the average K-value yielded by pit-bailing tests on holes of various diameters and depths was 31 m/day as compared to an average value of 37 m/day obtained with one-dimensional and seepage meter methods. Geometry factors obtained from the augerhole method (extended to fit the geometry of the pit) yielded an average K-value of only 17 m/day. Thus, geometry factors derived from the piezometer method gave more reliable results than those derived from the augerhole method. In anisotropic soils, K in horizontal and vertical direction can be calculated from the K values obtained from two pits with different geometries.

PERSONNEL: Herman Bouwer, Robert C. Rice, and Gladys C. Auer

Table 1. Calculation of K with pit-bailing test using values of A_p/r from piezometer and augerhole methods.

Depth of pit below surface cm	L_c cm	D cm	r cm	L_c/r	Piezometer A_p/r	Piezometer K m/day	Augerhole A_a/r	Augerhole K m/day
4	1	66	7.5	0.133	8.0	34.7	17.4	15.9
4	1	66	15.0	0.067	7.4	35.6	18.3	14.9
4	1	66	30.0	0.033	7.1	31.5	20.0	11.2
5	2	65	7.5	027	9.5	30.2	17.0	16.8
5	2	65	15.0	0.133	8.0	28.6	17.5	13.1
5	2	65	30.0	0.067	7.5	31.0	19.0	12.2
7	4	63	7.5	0.53	11.2	30.2	16.7	20.2
7	4	63	15.0	0.27	9.5	27.2	16.8	15.4
7	4	63	30.0	0.13	8.2	31.7	17.2	15.1
10	7	60	7.5	0.93	13.5	24.8	17.6	19.0
10	7	60	15.0	0.47	11.2	29.0	16.8	19.3
10	7	60	30.0	0.23	9.3	34.4	16.7	19.1
15	12	55	7.5	1.6	15.0	25.1	19.0	19.8
15	12	55	15.0	0.8	13.1	28.0	17.2	21.3
15	12	55	30.0	0.4	11.3	32.0	17.1	20.6
20	17	50	15.0	1.13	13.5	29.4	18.5	21.4
20	17	50	30.0	0.57	12.4	31.9	17.9	21.6

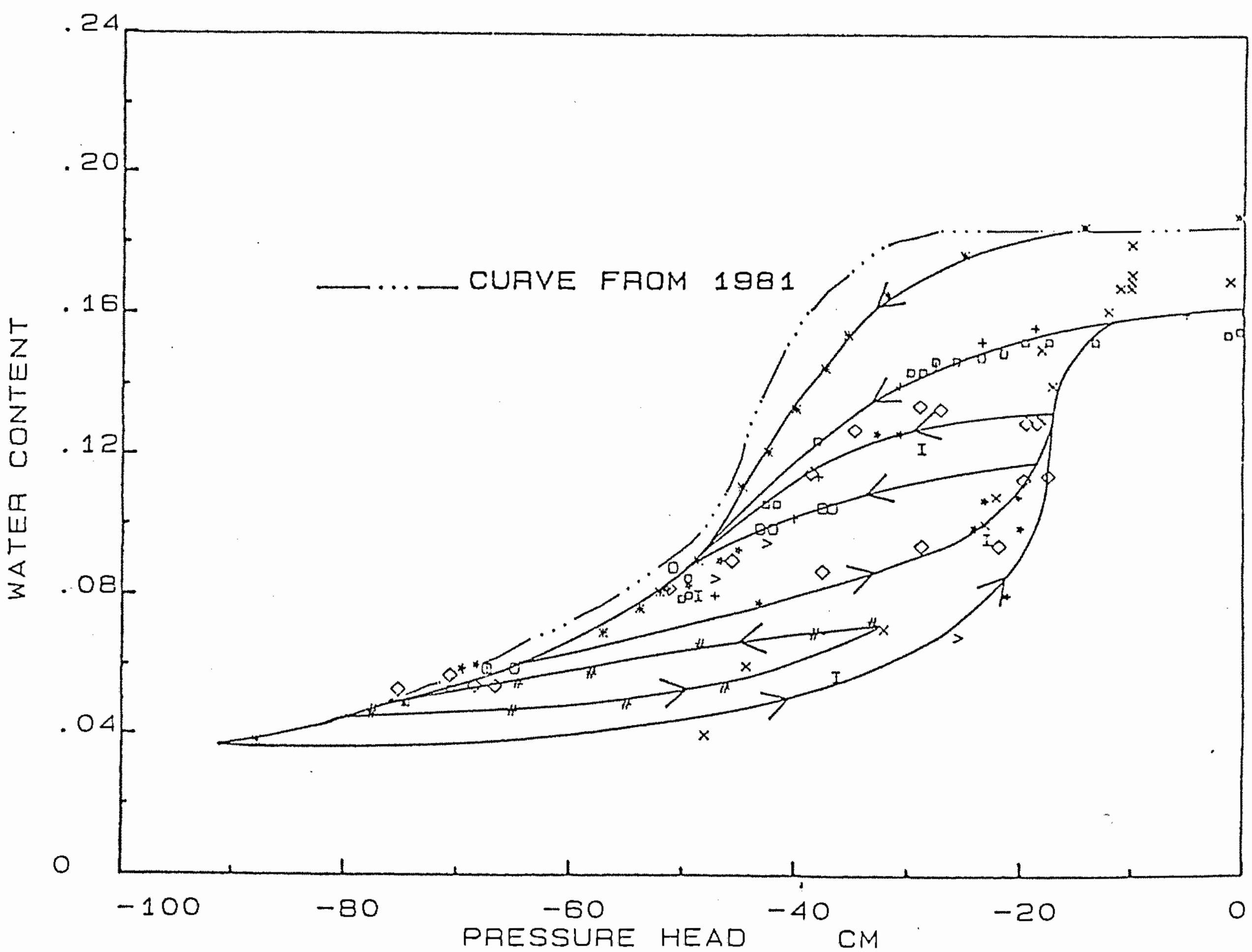

Figure 1. Water content-pressure head relationship for sand-boulder column including rewetting and hysteresis. The different symbols represent different tensiometers.

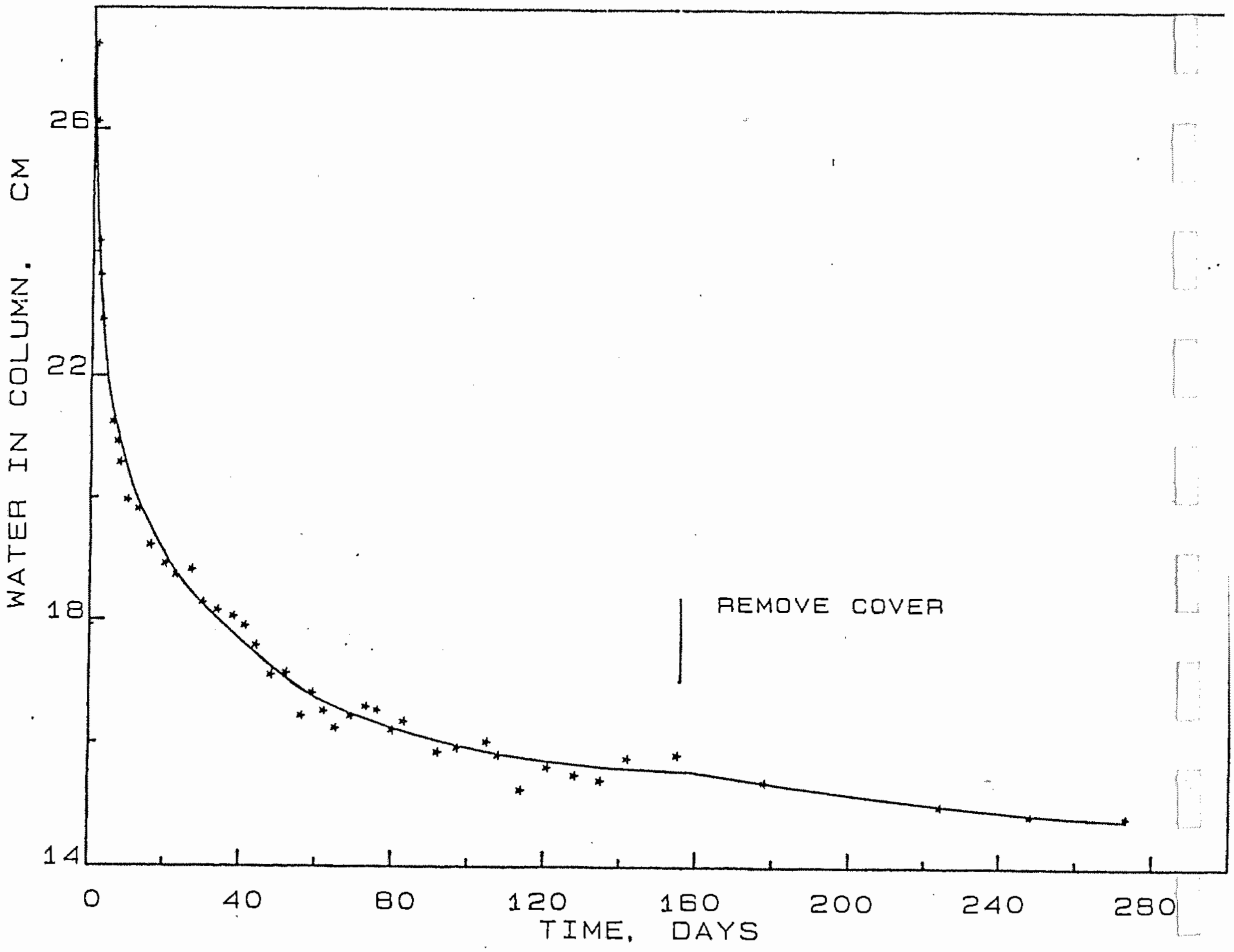

Figure 2. Total water in sand-boulder column during drainage. Column was covered for first 154 days.

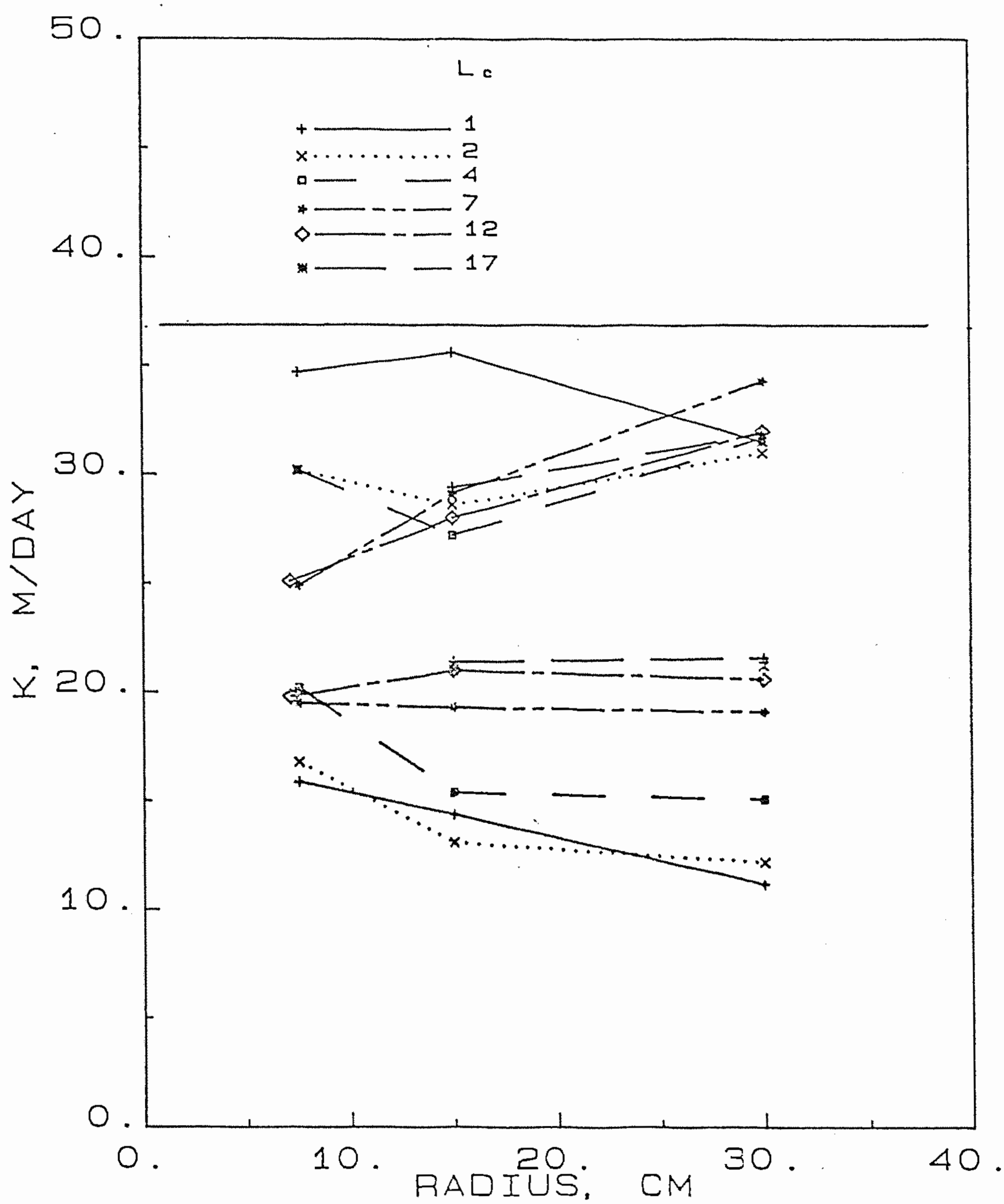

Figure 3. K-values obtained with pit-bailing method with piezometer-derived geometry factors (top group of curves) and with augerhole-derived geometry factors (bottom group of curves).

TITLE: LONG-TERM EFFECT OF IRRIGATION ON RECHARGE AND QUALITY OF GROUNDWATER

NRP: 20790 CRIS WORK UNIT: 5510-20790-005

I. Field Measurement of Deep Percolation Rates

INTRODUCTION:

Most of the world's agricultural land is underlain by groundwater. Particularly in arid areas, a significant proportion of groundwater recharge results from excess water which percolates downward below the crop root zone. The quantity and quality of this recharge water is at least partially dependent upon agricultural management. The percolating water contains salts and often fertilizer, pesticide, and herbicide residues which may pose environmental hazards when present in groundwater. Thus, protection of groundwater resources depends upon proper monitoring and control of deep percolation water quantity and quality.

Reliable methods for measuring deep percolation rates in the field are lacking. Deep percolation losses typically are estimated from water application and evapotranspiration data. Any errors in these measurements thus are incorporated into derived percolation estimates. In addition, very little information is available on the spatial and temporal variability of deep percolation rates. Clearly, there is a need for development of techniques to independently measure deep percolation rates and their relation to agricultural management.

The objective of the current research is to devise and test methods for measuring and predicting deep percolation rates. A further objective is the evaluation of management techniques to control deep percolation water quality and quantity for protecting and extending groundwater resources.

PROCEDURES:

1. Field plot

An instrumented field plot was established on the back lawn of the U. S. Water Conservation Laboratory (Fig. 1). The 6.1 m x 6.1 m plot is isolated from the surrounding soil by a 40-cm wide sheet-metal border set 20 cm into the ground. Four 1.8 m x 1.8 m sub-plots, defined by sheet metal borders, are centered within the larger plot. The sub-plots received most of the instrumentation and measurements will be concentrated within these areas, although the entire 6.1 m x 6.1 m plot will receive the same treatments. The 1.2-m wide area between the inner and outer plots serves as a buffer zone to minimize border effects. The separate sub-plots were set up as such to minimize differences in water application due to differences in infiltration rates.

Centered in each sub-plot is a neutron-probe access tube installed to a depth of 300 cm. Surrounding each access tube are seven soil-water solution samplers installed at depths of 30, 60, 100, 140, 180, 240, and 300 cm, or 28 samplers for the four sub-plots. The samplers are 2.2-cm diameter x 5-cm long ceramic cups (1-bar, high-flow, Soil Moisture Equipment Company), epoxy-bonded to 2.2-cm diameter copper tubing. The samplers are designed to allow evacuation of air and subsequent removal of collected soil-water samples.

Each sub-plot contains three pressure-transducer tensiometers, for a total of 12 tensiometers. Tensiometer depths are 10, 20, 30, 40, 60, 80, 100, 140, 180, 220, 260, and 300 cm. The tensiometers are designed to be connected to an automatic data collection system.

Four additional neutron-probe access tubes, to a depth of 300 cm, are installed in the buffer area (Fig. 1). Installed, but not shown in Fig. 1 is a distribution system to deliver water to each of the sub-plots and the buffer area through separate metered water lines.

2. Soil Sampling

Neutron-probe access holes were excavated with a king tube/hydraulic press assembly which allowed collection of intact soil cores at approximately 20-cm intervals. The core samples were 4.2 cm in diameter. Cores were trimmed as carefully as possible to 10.0-cm lengths to allow accurate bulk density determinations.

The core samples were placed in tared weighing cans. Air-dry and oven-dry core weights were obtained for calculating field moisture contents with depth. Core samples from the four sub-plots were analyzed for relative percentages of sand, silt, and clay.

Neutron probe readings were taken after installation of the access tubes to allow development, with core sample moisture data, of a calibration curve for each hole.

RESULTS AND DISCUSSION:

Tables 1-4 present moisture content, bulk density, and particle size data for core samples from sub-plots 1-4, respectively. The clay content versus depth relationships are plotted in Fig. 1. Although there is some variability in clay contents among the four holes at a given depth, values generally lie within ±4% of one another for corresponding samples. The clay content increases from a value of about 25% near the surface to approximately 35% at 90 cm. The clay percentage drops to about 30% in the 120-cm depth range, then rises to about 40% (except in sub-plot #4) near 150 cm. Below 150 cm there is a gradual decrease in clay percentage down to the maximum sampled depth of 300 cm. The increasingly coarse texture encountered at the lower depths was associated with increasing occurrence of rock fragments in the core samples. Large rock fragments, which prevented penetration of the king tube, were encountered at about 300 cm when the access tube holes were prepared. This observation, along with the noted increase in textural coarseness, suggests that an alluvial sand-gravel-boulder matrix, common in the Salt River Valley, occurs below 300 cm at the field plot site.

The measured volumetric water contents in the four profiles ranged between 14 and 26%. These moisture contents corresponded to neutron probe count ratios of roughly 0.56 to 0.94 (Table 5). Calibration curves developed from these data thus represent a fairly narrow range of soil water contents.

II. Identification and Analysis of Tracers for Soil-Water Studies

INTRODUCTION:

Measurement of water transfer within and beneath the rootzone requires physical or chemical means of following the movement of water. Predicting the mobility of toxic organic compounds, heavy metals, or other potential water-transportable pollutants likewise depends upon an ability to measure the movement of water within the soil. Tracers, chemicals which move with the water, are particularly useful in this regard since individual pulses of water (as from a single irrigation event) can be followed. Thus, the influence of water management, crop type, climatic changes, etc. on soil water status and deep percolation can be evaluated. Having several different tracers makes it possible to follow successive pulses of water within a single soil mass, allowing an evaluation of temporal as well a spatial variability in soil water movement and determination of how rapidly individual water pulses are dampened out.

The objective of this research is to identify a series of tracers suitable for soil water studies and to develop procedures for their rapid and quantitative analysis.

IDENTIFICATION OF POTENTIAL TRACERS:

There are three main requirements for a suitable soil-water tracer: (1) the tracer must move with the water, i.e., there must not be significant sorption or degradation of the tracer; (2) the tracer must be exotic, i.e., be absent from the natural environment or present at such low levels as to represent a negligible background; and (3) it must be possible to distinguish and quantify the tracer within a matrix such as the soil solution.

Although a large variety of tracers have been used for soil-water and groundwater studies (Davis et al., 1980), $^{3}H_2O$, NO_3^-, Cl^-, and Br^- have been most commonly used by soil scientists. The environmental hazards associated with radioactive $^{3}H_2O$ prevent its use in large-scale field studies. NO_3^- is subject to various chemical and biological transformations making its use in long-term studies questionable. Cl^- and Br^- are suitable from a stability and safety standpoint, and are generally considered good soil-water tracers, although anion exclusion can cause such negatively charged species to move faster than the water (Bohn et al., 1979). Cl^- suffers from the disadvantage of being present naturally in rather high concentrations, particularly in arid-region soils. Br^-, on the other hand, shows very low background levels for most soils.

A group of organic compounds which show promise as potential soil-water tracers are fluorinated derivatives of benzoic acid. Benzoic acid itself is a good soil-water tracer (Malcolm, 1982), but is subject to degradation by soil microorganisms (Granato et al., 1982). Pentafluoro benzoic acid and m-trifluoromethyl benzoic acid have been used as groundwater tracers (Stetzenbach, et al., 1982) and appear to be resistant to chemical and biological degradation.

A series of commercially-available fluorinated benzoic acid derivatives have been obtained and are undergoing evaluations of stability and analytical methodology (Table 6). The inorganic ions Br^-, I^-, and SCN^- are also undergoing evaluation. Like Br^-, I^- and SCN^- are typically present at very low levels in the natural environment and represent potential soil water tracers.

ANALYSIS OF TRACERS:

High-performance liquid chromatography (HPLC) is the analytical technique of choice for quantifying the organic and inorganic anions under study. HPLC should allow quantifying each of several tracers in a mixture (as when successive water pulses are traced) in a single analysis. Detection limits for the compounds of interest are in the range of a few nanograms with ultraviolet (UV) spectrophotometric detection, allowing the use of small (less than 1 mℓ) soil water samples.

An HPLC system including a variable wavelength UV detector has been procured and set up. Several different analytical columns have been procured and are in the process of being evaluated as to their efficiency in separating mixtures of the organic and inorganic anions. Initial work centered on adapting a literature analysis (Cortes, 1982) for a mixture of inorganic anions and acids of a similar pKa range to those of interest using an amino column (Dupont Zorbax NH_2) in the anion exchange mode. This column was found to lose efficiency rapidly under the conditions required for compound separation, making it unsuitable for extended routine use. Use of an octadecyl silane column (IBM Octadecyl) did not allow separation of the inorganic species. Current work with a strong anion exchange column (Whatman Partisil SAX-10) shows greater apparent column stability and potential for good separation of the species of interest. Optimization of the HPLC analysis is continuing.

EVALUATION OF TRACERS:

1. Field evaluation

As discussed above, a suitable soil-water tracer must not be significantly sorbed or degraded in the environment in which it is to be used. An experiment is in progress to evaluate the performance of the potential tracers under field conditions.

A field plot has been set up. The plot consists of a 1.8 m x 1.8 m square isolated from the surrounding soil by a 20-cm high sheet metal barrier set approximately 20 cm into the ground. A neutron-probe access tube, set to a depth of 234 cm, is in the center of the plot. Two porous ceramic suction samplers are placed 180° opposite from one another, each at a distance of 38 cm from the plot center. The shallow sampler is placed at a depth of 100 cm below the soil surface, while the deep sampler is at 180 cm below the surface.

This plot will be irrigated with water spiked with a mixture of all the potential tracers under consideration. Initial tracer concentrations will depend upon the sensitivity of HPLC analysis. Assuming likely detection limits in the range of 10 to 1000 ppb, initial concentrations in the range of 1 to 100 ppm will allow accurate determination of relative tracer concentrations on the order of 1%. Following irrigation, soil-water samples will be extracted regularly using the suction samplers and analyzed for tracer concentrations.

Br^- will serve as the index tracer. In any soil-water sample, the relative concentration of each tracer should be similar to the relative concentration of Br^- if no significant soil interactions occur. This test will integrate the many physical, chemical, and biological factors affecting tracer suitability and should indicate which of the compounds under consideration will make useful soil-water tracers.

2. Background levels

To determine whether native Br^- would represent a significant background, Br^- levels were measured for several soil and water samples. No background concentrations of the fluoroorganic compounds listed in Table 6 are expected since these are synthetic materials not present in the environment. Background levels of I^- and SCN^-, also expected to be very low, have not yet been determined.

The samples for which Br^- background levels were determined included U. S. Water Conservation Laboratory (USWCL) tap water, which will be used as irrigation water, as well as a saturation extract of a surface (0-15 cm) sample of the Avondale soil from the field site. Five water samples from an experimental setup at Los Alammos Scientific Laboratory (LASL) were also checked for native Br^-. The Los Alamos facility, which includes several large (3 m diameter x 8 m length) columns or "caissons" packed with crushed volcanic tuff, will be used for tracer experiments in 1983.

Analyses were performed using a colorimetric procedure (Rand et al., 1976). Samples were run neat, or, where sample volume was limited, were diluted. Results of the analyses are presented in Table 7. USWCL tap water and LASL input water each showed native Br^- concentrations of less than 0.5 ppm. Some of the other samples showed greater Br^- levels, but none of the samples showed more than 1.6 ppm Br^-. The higher Br^- levels were associated with water samples which had leached through large quantities of volcanic tuff. These levels of Br^-, which would represent less than 2% of an initial Br^- tracer level of 100 ppm, will not interfere with interpretation of Br^- tracer data.

3. Sorption of Bromide

Laboratory equilibrium tests were made on surface samples of Avondale so and LASL tuff to determine whether retention of Br^- would be a cause or concern. Ten g of solid was added to 20 mℓ of 10 ppm or 1000 ppm Br^- solution (as KBr) in 50 mℓ polypropylene centrifuge tubes, and shake intermittently over a 20-hour period. After centrifugation, the supernatants were analyzed for Br^- concentration. Results are presented i Table 8. Avondale soil apparently removed some Br^- from solution at a 10-ppm initial concentration, although the fraction removed differed for repeat experiments performed on different days. There was no evidenc o removal from the 1000 ppm Br^- solution. The tuff samples did not remo e any Br^- from solution, and in fact, solution Br^- levels appeared to increase somewhat for the 10-ppm initial concentration, possibly due to native Br^- (see Table 7). Some equipment problems were experienced d ri these analyses and the absolute values of the data points may be questionable. Nonetheless, there is an indication here that the Avondal soil has some retention capacity for Br^-. This possibility will be checked more thoroughly using HPLC for Br^- quantification, which should eliminate some of the data variability.

Retention of an inorganic anion such as Br^- by a basic pH soil such a t Avondale is a surprising result. In a similar batch sorption study with two soils and a 5-ppm initial Br^- concentration, Tennyson and Settergren (1980) found apparent removal and additions of Br^- on the order of th variations shown here. They attributed such apparent soil-Br^- interacti as likely due to experimental errors in concentration measurements.

Retention or release of Br^- by the porous ceramic cups used in the fi ld plot was checked. Although there was again considerable scatter in the colorimetric measurements, no significant amount of Br^- was removed f om 100 mℓ of 10-ppm or 1000-ppm Br^- drawn through individual cups. One hundred mℓ of distilled water drawn through individual pre-washed cups showed no measurable Br^- contamination.

4. Degradation of fluorinated benzoic acid derivatives

During development of HPLC analytical techniques for various potentia tracers, the apparent degradation of several of the tracers was noted Individual 50-ppm solutions (in water) of each of the fluorinated compounds listed in Table 6 were prepared, along with a mixture of six of t organics and Br^- (50 ppm each). These solutions were stored at room temperature, intermittently exposed to sunlight, for a period of approximately 40 days. During this time, the chromatograms for o-, m-, and p-fluorobenzoic acid changed dramatically. Figure 3 shows a chromatogr m a 7-compound mixture of tracers with the retention times of individua compounds indicated. Note the absence of a peak at 2.5 minutes. Figure presents individual chromatograms for the three monofluorobenzoic aci isomers after storage for 40 days at room temperature. The height a d area of each individual compound peak is reduced compared to the respective value in the mixture, and the peak for p-fluorobenzoic acid has disappeared altogether. The peak at 2.5 minutes is smallest for m-fluorobenzoic acid, which showed the least reduction in peak size for the parent compound, and largest for the p-fluoro isomer. The peaks at 2.5 minutes almost certainly represent similar degradation products which were only weakly retained under the chromatographic conditions used. There are reports in the literature of microbial degradation of o-, m-, and p-fluorobenzoic acid under controlled laboratory conditions (Engesser et al., 1980; Schreiber et al., 1980). Since the likelihood of degradation of o-, m-, and p-fluorobenzoic acid in the soil environment would appear to be high, these three compounds have been dropped from further consideration as soil water tracers.

SUMMARY AND CONCLUSIONS:

Field Measurement of Deep Percolation Rates

A field plot was established for purposes of testing methods for measuring and predicting deep percolation rates. The 6.1 x 6.1 m plot was instrumented with neutron probe access tubes, soil-water suction samplers, and pressure transducer tensiometers. The eight access tubes, four in the central experimental area and four in the outer buffer area, were installed to a depth of 300 cm. Twenty-eight suction samplers, distributed in four replications within the central plot area, were installed at seven depths from 30 cm to 300 cm. The 12 tensiometers, placed at depths of 10 to 300 cm, were distributed within the central plot.

Core samples taken during access tube installation were analyzed for particle size distribution, moisture content, and bulk density. Particle size distributions for the four core samples from the inner plot showed similar trends with depth. Increasing coarseness of the soil samples at the lower depths, along with the increasing occurrence of rock fragments near 300 cm, indicated that a sand-gravel-boulder matrix was being approached at this depth.

Neutron probe count data along with volumetric water content measurements allowed development of neutron probe calibration curves within the range of 14 to 26% moisture content.

Further characterization of the field plot will include determination of moisture content-pressure head-hydraulic conductivity relationships, and evaluation of effects of irrigation management and water content changes on the mobility of conservative tracers. These measurements will be used for developing field procedures for measuring deep percolation rates.

Identification and Analysis of Tracers for Soil-Water Studies

A series of organic and inorganic anions with potential as soil water tracers was identified and obtained. The compounds included various fluorinated derivatives of benzoic acid, tetrafluorophthalic acid, Br^-, I^-, and SCN^-. These compounds share the characteristic of being present naturally at low concentrations and can be quantified by a single analytical technique.

A high-performance liquid chromatographic (HPLC) procedure is being optimized for simultaneous identification and quantification of individual tracers within a mixture. A separation based on the use of an anion exchange analytical column shows the greatest promise.

A 1.8 m x 1.8 m field plot for tracer evaluation was established. The plot, instrumented with a neutron-probe access tube and soil solution samplers, will be used to measure tracer mobilities in relation to Br^-. Retardation, degradation, or other causes for non-conservative movement will be reflected in differences in relative concentrations of individual tracers over time.

Background levels of Br^- were found to be low for USWCL tap water and for a saturation extract of soil from the field site. The Br^- level in the tap water was 0.38 ppm, while no Br^- was detectable in the extract of Avondale soil. Br^- levels in extracts and water samples from Los Alamos Scientific Laboratory were likewise very low. The highest Br^- levels detected, 1.6 ppm, were from water samples which had leached through larg quantities of volcanic tuff.

Laboratory equilibration with 10-ppm and 1000-ppm Br^- solutions showed some apparent Br^- sorption by the Avondale soil. Due to considerable scatter in the data values obtained using a colorimetric procedure, Br^- retention will be checked again using HPLC for Br^- quantification.

Degradation of o-, m-, and p-fluorobenzoic acid under laboratory conditions was noted within 40 days. p-Fluorobenzoic acid appeared to be completely degraded during this period. The o-, and m-isomers were more stable, with only slight degradation of the m-isomer noted. Degradation of these organic species would likely be enhanced in the soil environment therefore, they are no longer being considered as potential tracers.

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Table 1. Physical characteristics of soil core samples. Deep percola io study plot, Hole No. 1. Particle size classes in microns (% by weight); GRVMST = gravimetric moisture content in g/g x 100; Bulk density in g/cm^3; Θ = Volumetric moisture content in cm^3/cm^3 x 100.

Depth (cm)	Below 2	2-20	20-50	50-2000	GRVMST	Bulk Dens.	Θ
10	21.3	23.1	20.6	35.0	9.4	1.62	15.2
30	32.0	34.0	18.3	15.7	13.6	1.43	19.5
50	32.6	24.7	30.4	12.3	13.1	1.41	18.4
70	34.5	25.6	24.3	15.6	13.0	1.39	18.1
90	34.0	23.5	20.2	22.3	11.7	1.43	16.7
110	25.8	16.2	22.4	35.6	9.2	1.46	13.5
130	22.8	19.2	19.7	38.3	10.0	1.48	14.8
150	40.0	16.8	18.2	25.0	16.2	1.47	23.8
170	33.0	21.0	21.1	24.9	15.4	1.55	23.3
190	34.3	26.5	18.9	20.3	16.2	1.59	25.8
210	28.9	22.3	20.8	28.0	14.6	1.68	24.6
230	21.0	20.5	23.2	35.3	12.8	1.71	21.9
250	20.5	25.7	27.6	26.2	13.5	--	--

Table 2. Physical characteristics of soil core samples. Deep percolatio study plot, Hole No. 2. Particle size classes in microns (% by weight); GRVMST = gravimetric moisture content in g/g x 100; Bulk density in g/cm^3; Θ = Volumetric moisture content in cm^3/cm^3 x 100.

Depth (cm)	Below 2	2-20	20-50	50-2000	GRVMST	Bulk Dens.	Θ
10	23.5	23.5	24.4	28.6	14.8	1.36	20.2
30	29.0	27.0	24.2	19.8	14.2	1.42	20.2
50	32.0	26.6	23.5	17.9	14.1	1.49	21.1
70	31.2	26.3	24.7	17.8	14.3	1.45	20.7
90	34.8	24.9	20.0	20.3	14.0	1.45	20.3
110	29.0	18.0	22.6	30.4	10.8	1.50	16.2
130	31.8	16.4	20.6	31.2	12.2	1.49	18.2
150	41.8	16.9	17.1	24.2	15.3	1.52	23.3
170	31.8	22.5	22.9	22.8	14.4	--	--
190	29.5	25.3	23.4	21.8	14.6	--	--
205	25.4	22.8	23.0	28.8	12.8	--	--
220	21.3	20.9	25.1	32.7	12.7	--	--
240	18.8	23.7	29.7	27.8	13.3	--	--
260	17.2	23.1	30.0	29.7	12.5	--	--
280	15.0	21.8	25.2	38.0	--	--	--
300	14.2	12.8	16.1	56.9	--	--	--

Table 3. Physical characteristics of soil core samples. Deep percolation study plot, Hole No. 3. Particle size classes in microns (% by weight); GRVMST = gravimetric moisture content in g/g x 100; Bulk density in g/cm^3; Θ = Volumetric moisture content in cm^3/cm^3 x 100.

Depth (cm)	Below 2	2-20	20-50	50-2000	GRVMST	Bulk Dens.	Θ
10	27.5	23.5	22.0	27.0	12.0	1.35	16.3
30	25.0	23.8	23.6	27.6	12.3	1.33	16.4
50	29.8	28.2	24.4	17.6	14.7	1.39	20.4
70	29.2	22.8	30.0	18.0	13.7	1.39	19.1
90	37.3	23.2	21.4	18.1	14.9	1.45	21.5
110	29.6	18.9	22.6	28.9	11.4	1.44	16.4
130	34.0	11.0	23.8	31.2	13.3	1.53	20.3
150	39.2	20.1	16.7	24.0	16.5	1.44	23.7
170	33.2	26.1	19.0	21.7	16.5	1.53	25.2
190	34.0	30.8	18.0	17.2	16.8	1.53	25.7
210	25.8	21.5	23.7	29.0	15.6	--	--
230	14.0	19.2	34.3	32.5	12.1	--	--
245	23.5	12.5	37.0	27.0	14.2	1.58	22.4
260	14.8	22.0	34.4	28.8	14.1	1.65	23.2
280	12.2	20.0	31.1	36.7	--	--	--

Table 4. Physical characteristics of soil core samples. Deep percolation study plot, Hole No. 4. Particle size classes in microns (% by weight); GRVMST = gravimetric moisture content in g/g x 100; Bulk density in g/cm^3; Θ = Volumetric moisture content in cm^3/cm^3 x 100.

Depth (cm)	Below 2	2-20	20-50	50-2000	GRVMST	Bulk Dens.	Θ
10	23.8	20.8	24.3	31.1	12.5	1.49	18.7
30	30.7	28.8	24.4	16.1	15.2	1.46	22.2
50	28.0	25.8	27.7	18.5	14.2	1.45	20.6
70	37.0	25.8	22.0	15.2	15.8	1.51	23.8
90	34.1	21.7	21.9	22.3	14.6	1.46	21.3
110	26.6	15.2	22.2	36.0	10.6	1.51	16.0
130	26.7	16.1	21.0	36.2	10.9	1.50	16.4
150	28.3	24.0	20.8	26.9	15.9	1.42	22.5
170	34.8	25.4	19.1	20.7	16.1	1.51	24.3
190	38.4	16.4	19.0	26.2	16.4	1.54	25.3
210	21.8	23.7	24.6	29.9	14.5	1.59	23.1
230	18.2	25.1	27.9	28.8	14.0	1.70	23.8
250	14.0	28.7	29.1	28.2	15.0	1.63	24.4
270	13.5	20.0	28.1	38.4	13.5	1.67	22.5
290	13.5	15.6	19.1	51.8	--	--	--

Table 5. Neutron probe count ratios with depth.

Hole No.	1	2	3	4	5	6	7	8
Std. Count	11680.8	11684.5	11735.7	11661.0	11730.5	11646.5	11762.4	11[illegible]17
Depth (cm)	Count Ratio with Depth							
20	.6408	.7073	.7531	.7804	.7191	.6831	.6968	.[illegible]43
40	.7251	.7709	.7890	.7940	.7618	.8175	.7783	.[illegible]46
60	.6859	.7582	.7809	.7691	.7267	.8042	.6898	.753
80	.6795	.8605	.8185	.8629	.7408	.8970	.7273	.[illegible]26
100	.5795	.7186	.6880	.7503	.6396	.7989	.6288	.[illegible]27
120	.5524	.6492	.6387	.6717	.6266	.7247	.5993	.641
140	.7034	.8277	.8119	.8436	.7570	.8337	.8123	.[illegible]00
160	.8017	.8967	.8233	.8940	.8358	.8499	.9170	.[illegible]60
180	.8352	.9547	.8580	.9459	.8838	.9002	.9192	.[illegible]97
200	.8979	.9606	.8959	.9320	.8788	.9286	.8967	.924
220	.8852	.9012	.8838	.9457	.8225	.8656	.8631	.[illegible]96
240	.8773	.8940	.8579	.9258	.8674	.9171	.8721	.[illegible]94
260	.8378	.8877	.8641	.8763	.8128	.9365	.8622	.798
280	--	.8973	.7415	.7637	.6926	.8776	.8416	.[illegible]75

Table 6. Fluorinated benzoic acid derivatives undergoing evaluation.

Compound	pK_1	pK_2	Reference
o-fluorobenzoic acid	3.27		1
m-fluorobenzoic acid	3.86		1
p-fluorobenzoic acid	4.14		1
2,6-difluorobenzoic acid	--		
pentafluorobenzoic acid	1.74		2
o-trifluoromethyl benzoic acid	--		
m-trifluoromethyl benzoic acid	3.9		2
p-trifluoromethyl benzoic acid	--		
tetrafluorophthalic acid	--		
benzoic acid	4.19		1
phthalic acid	2.95	5.408	1

* References: (1) Martell and Smith, 1977
(2) Stetzenbach et al., 1982

Table 7. Background Br^- concentrations of soil extracts and water samples.

Sample	Br^- concentration (ppm)
USWCL tap water (8-30-82)	0.38
Avondale soil, saturation extract	0.00
LASL tuff, 1:1 extract	0.50
LASL input water (7-28-82)	0.45
LASL caisson A outflow (7-28-82)	0.20
LASL caisson B outflow (7-28-82)	1.6
LASL caisson B suction sample (7-28-82)	1.6

Table 8. Bromide interactions with Avondale soil and LASL tuff.

Sample	Date	Nominal Initial Br^- concentration (ppm)	Final Br^- concentration (ppm)
Blank (no soil)	8-30-82	10	9.03
Avondale	"	"	7.33
Avondale	"	"	7.33
Blank (no soil)	9-14-82	10	9.63
Avondale	"	"	9.08
Avondale	"	"	9.08
Blank (no soil)	8-30-82	1000	909
Avondale	"	"	903
Avondale	"	"	948
Tuff	8-30-82	10	10.1
Tuff	"	"	10.1
Tuff	8-30-82	1000	932
Tuff	"	"	903

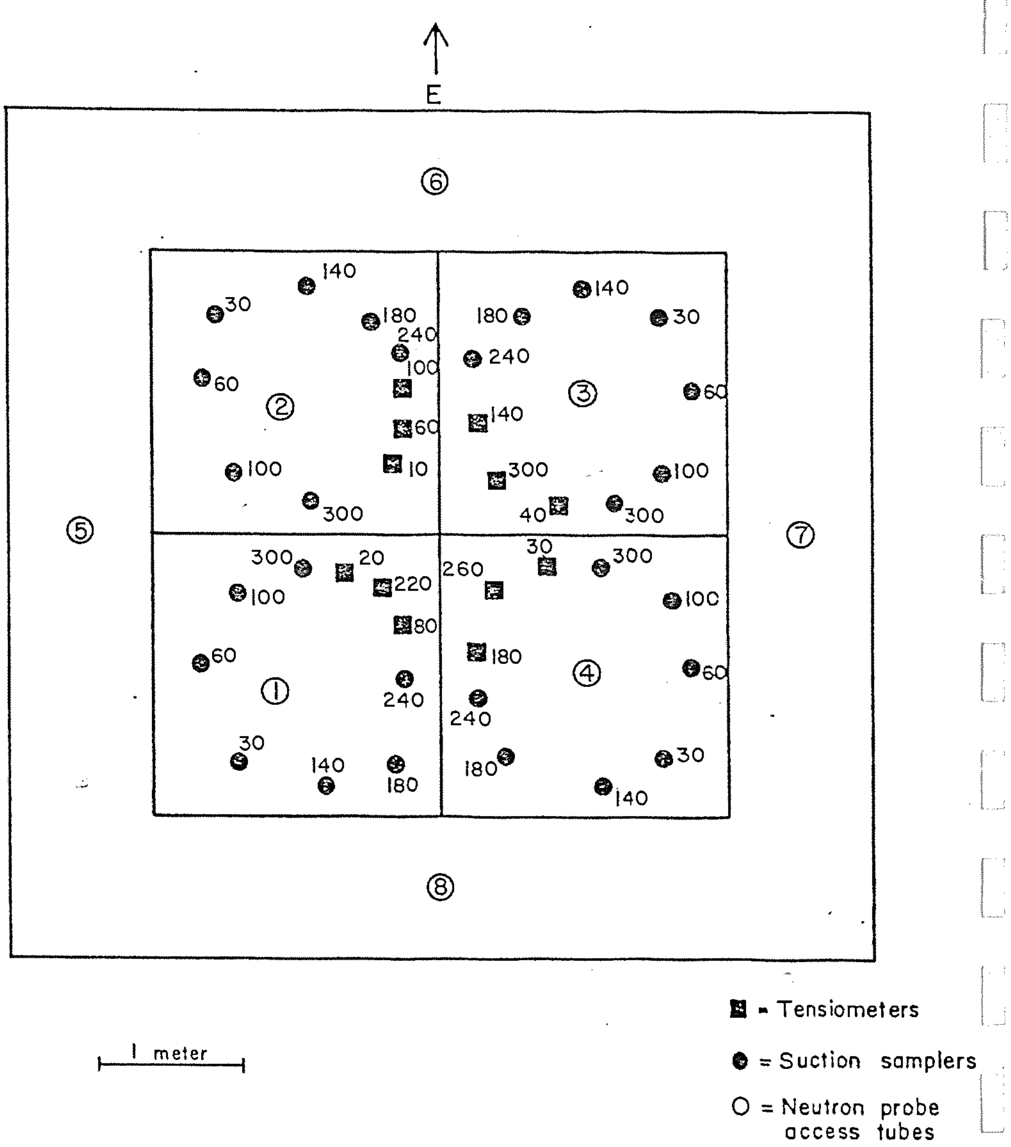

Figure 1. Layout of deep percolation study field plot. Numbers indicate sampler and tensiometer depths in cm.

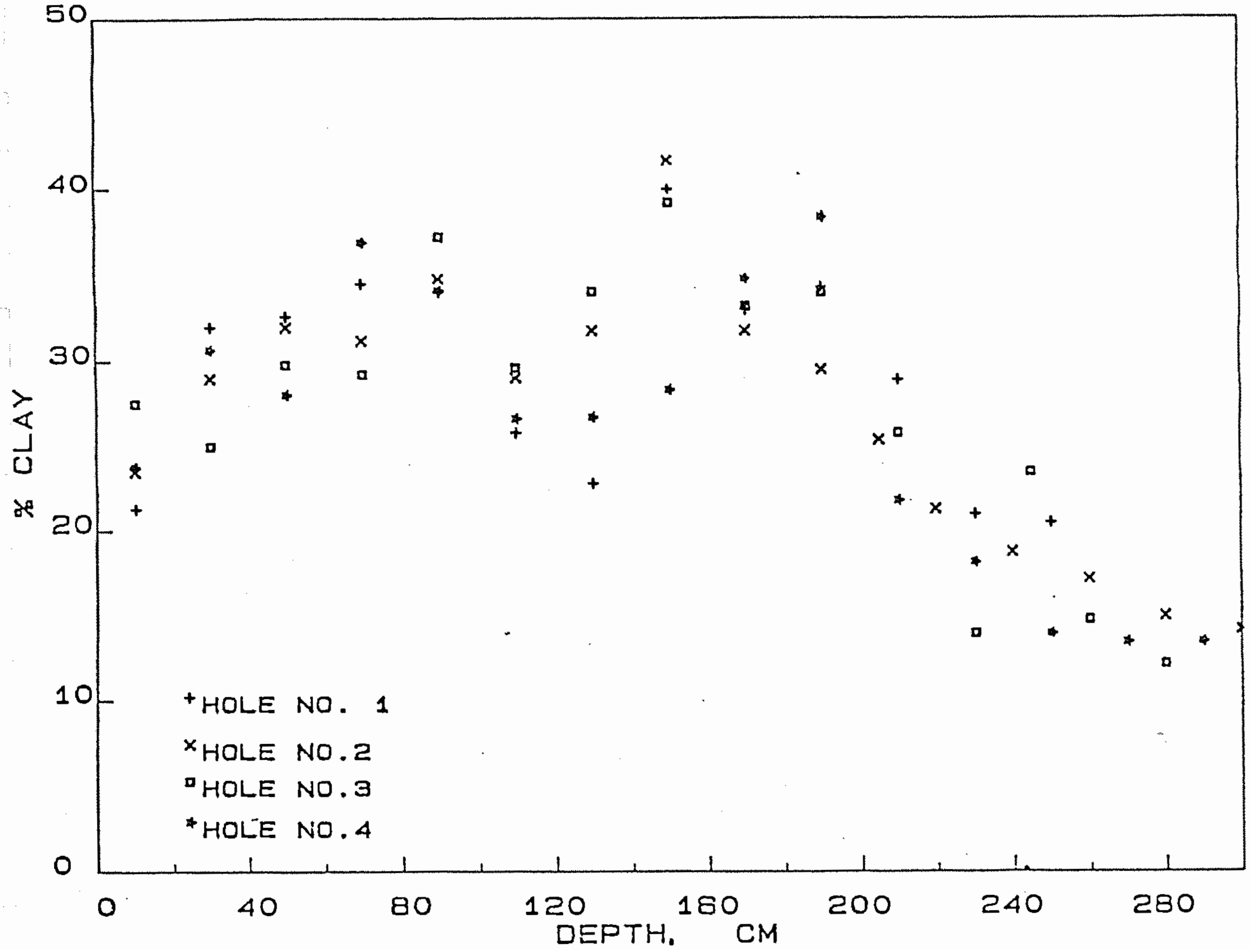

Figure 2. Percent clay with depth for core samples from deep percolation field plot.

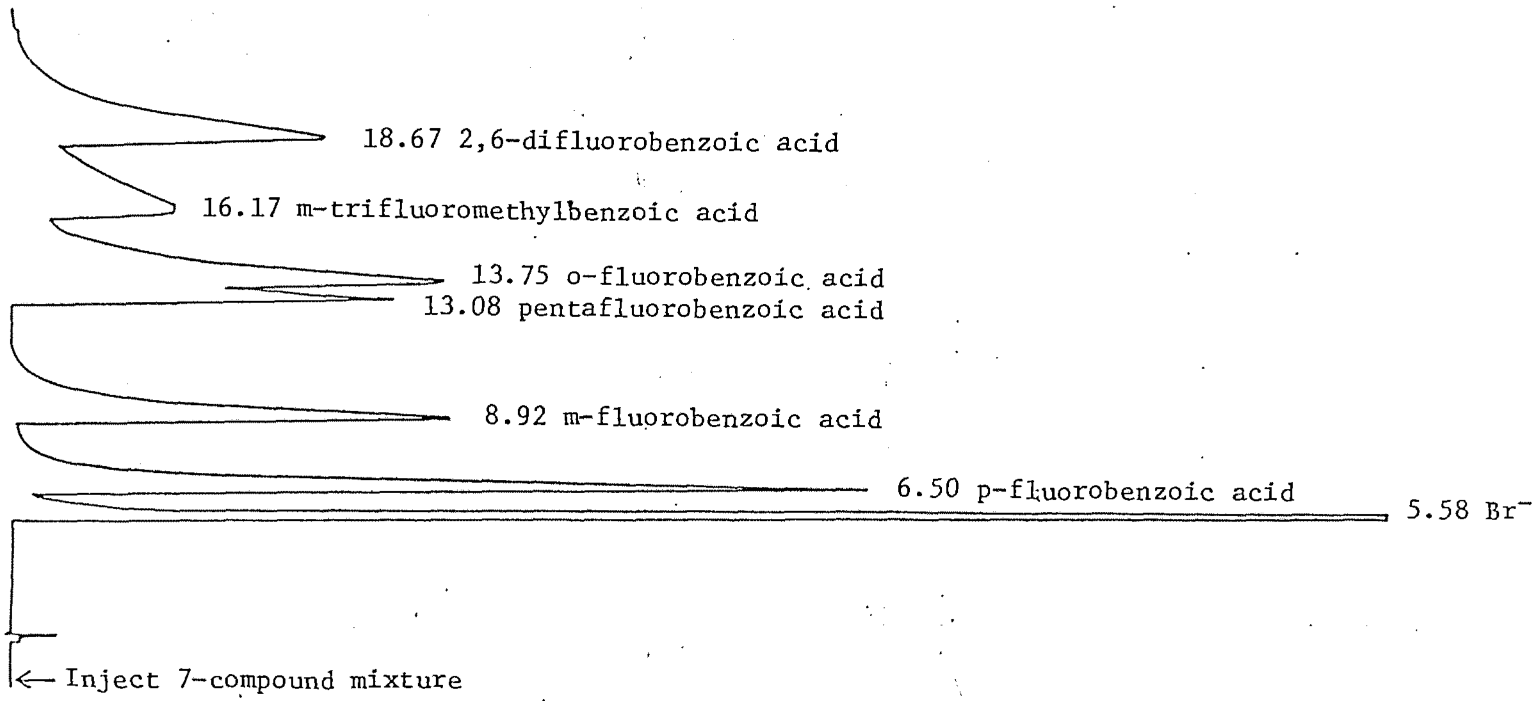

Figure 3. High performance liquid chromatogram of a 7-compound tracer mixture. Numbers are retention times in minutes. Chromatographic conditions:

Column:	Dupont Zorbax NH_2, 25 cm
Mobile Phase:	0.03 M H_3PO_4, pH adjusted to 3.2 with NaOH.
Flow Rate:	2 mℓ/min
Detection:	Waters 480, 205 nm, 0.1 AUFS
Sample:	20 μℓ, 50 ppm of each compound

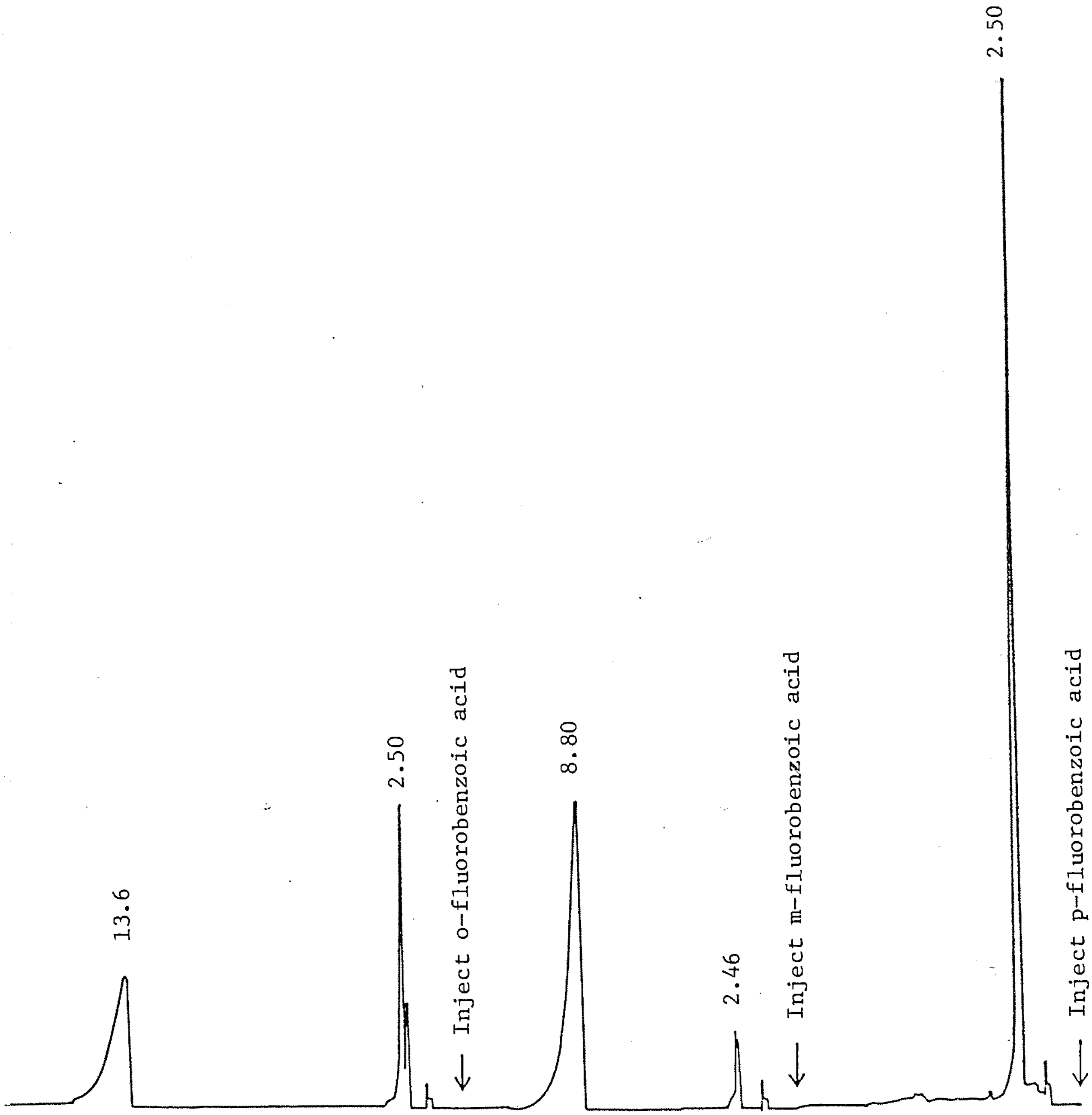

Figure 4. High performance liquid chromatograms of o-, m-, and p-fluorobenzoic acid. Chromatographic conditions as in Fig. 3.

APPENDIX

LIST OF PUBLICATIONS AND

MANUSCRIPTS PREPARED IN 1982

MS. No.

NRP 20740 IMPROVE IRRIGATION AND DRAINAGE OF AGRICULTURAL LAND. (Irrigation and Hydraulics Research Group).

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In Press:	BROOKS, G. B. and KIMBALL, B. A. Simulation of a low-cost method for solar-heating an aquaculture pond. Energy in Agriculture.	868
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RICE, R. C., and BOUWER, H. Soil-aquifer treatment using primary effluent. To be submitted to J. Water Pollut. Control Federation.