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9. ABSTRACT

This two-part publication contains, in Part I, 71 abstracts of journal articles, reports, and theses on the subject of trickle (drip) irrigation. The abstracts were selected from 355 in a computer printout produced from a search of the literature in the Northeastern Water Resource Information Terminal, Engineering Library, Cornell University. The literature citations and abstracts are classified into five groups: General Progress; Physics and Mathematical Models; Management and Mechanics; Water Use, Salinity, and Fertilization; and Crop Response. Part II of this publication consists of 74 references taken from the Second International Drip Irrigation Congress Proceedings (July 7-14, 1974). The citations are organized under headings similar to those used in Part I.

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TRICKLE (DRIP) IRRIGATION

Abstracts of References

assembled by

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Part I.

ABSTRACTS AND BIBLIOGRAPHY OF REFERENCES ON TRICKLE (DRIP) IRRIGATION

References With Abstracts (July 1968-August 1974)

A. General Progress

Anonymous. 1972. Drip irrigation big success at Buena Vista Winery. Irrigation Journal, Vol. 22, No. 6, pp. 7-8, Nov.-Dec., 1972.

A large drip irrigation system used at the Buena Vista Vineyards is described. The system seems to be very successful in supplying the needed water and also cuts both water use and cultivation costs.

Anonymous. 1972. Drip irrigation developer in Israel makes deal to market system in U.S. Irrigation Age, Vol. 6, No. 7, pp. 14-16, 39-40, Feb. 1972.

A new development in irrigation, developed and perfected in Israel, will be introduced on a major scale in the U.S. Symcha Blass of Tel Aviv, originator of trickle-root irrigation widely utilized in Israel and the Netafim Drip Irrigation Firm, its manufacturer, signed a licensing agreement in September with industrialist Howard Klein of Washington, D. C., who heads an agro-technical organization formed to install this system throughout the U.S.

Anonymous. 1972. Revolutionary drip irrigation system to be introduced in U.S. by agreement with Israeli developers. Citrus Industry., Vol. 53, No. 2, pp. 13-14, February 1972.

Trickle irrigation is widely used in Israel and the technology is being exported to the U.S. The "International Expert Panel Meeting on Irrigation" noted that the drip method is the world's advanced irrigation technique. Crop production may increase up to two times, and 30 percent less water is required. Ten years of intensive experience attest to the success of the method. Water conservation is highlighted. Trickle irrigation reduces migration of agricultural pollutants to streams and aquifers, and is especially effective in areas of sparse sandy soil and minimal rainfall. A fixed plastic network of fertilizer control head, main

fillers and main pipes places water on soil as a mixture of water and fertilizer directly plant roots. Regular irrigation at predetermined rates keeps soil moisture tension beneficially low while avoiding damage to leaves. Major successes are noted in Israel, Australia, South Africa, and Mexico under a variety of crops. Cucumbers, green peppers, oranges, grapes, strawberries, tomatoes, and melons are typical crops studied. Some marketing and equipment information is imparted.

Cole, E. 1971 (Oak Ridge National Laboratory, Tennessee Desalination Information Center). Subsurface and trickle irrigation: A survey of potentials and problems. (Available from the National Technical Service as ORNL-NDIC-9; $3 per copy, microfiche 95¢. Report ORNL-NDIC-9, November 1971).

Subsurface and trickle irrigation are not new ideas. However, at present in the U.S. they represent only a negligible portion of the land area under irrigation. During the past ten or twelve years a number of investigations have been made of these types of irrigation and their possible uses. Information is needed on the best types of applicators, system design, installation methods, operation, and the costs involved. The need for further development coupled with the need for extensive testing over a number of agricultural cycles, indicates that it will be several years before such systems are ready for widespread use. Even with further development of improved and less expensive equipment, the capital costs of such systems will be high. Present estimates range from $300 to $1000 per acre for row crops, assuming a water supply available at the site. It appears that the major application will be for high-value crops and for particular locations where water is scarce or expensive. The current use of similar irrigation in dry areas of Israel, where soil and water quality are poor, is good evidence that the high capital costs can be justified under the proper conditions. A very crude estimate of the cost of installing a subsurface-irrigaton system is given.

Davis, S. and S. D. Nelson. 1970 (University of California, Riverside). Subsurface irrigation today and tomorrow in California. American Society of Agricultural Engineers, National Irrigation Symposium Paper, University of Nebraska, Lincoln, November 1970.

Subsurface irrigation is the application of water under the soil surface that moves by capillarity into the root zone of the crop. Applying water at the surface in a similar manner is called trickle irrigation. Research on subsurface and trickle irrigation is being conducted by the Agricultural Research Service at Riverside, California. Objectives of the study are to: (1) Evaluate subsurface and trickle systems, (2) evaluate subsurface water movement, (3) compare subsurface and trickle systems with conventional irrigation systems,

(4) determine water use, and (5) determine whether production differences exist between conventional systems and subsurface systems. Although many research problems remain to be solved, the future of subsurface and trickle irrigation is promising. Applying water by subsurface and trickle irrigation is promising. Applying water by subsurface or trickle methods decreases waste of water and fertilizer. Reducing fertilizer losses reduces pollution in rivers and lakes. Subsurface and trickle irrigation offer a means of positively distributing irrigation water with minimum evaporation and deep percolation losses. Some commercially produced subsurface and trickle irrigation applicators are described.

Davis, Sterling. (University of California, Riverside). Subsurface irrigation, 1967 how soon a reality. Agricultural Engineering, Vol. 48, No. 11, pp. 654-655, November 1967.

The major reason for interest in subsurface irrigation is the possibility it holds for even, automatic water. Application combined with reduced evaporation losses. One of the crucial components of a subsurface irrigation system is the applicator which transfers water from the pipe to the soil. A successful applicator must have the qualities of durability, flow continuity, economy, easy installation, easy replacement, and resistance to root penetration. These qualities were evaluated for several underground water applicators. Applicators are described and their test performances discussed.

Fangmeier, D. D. (Arizona Agricultural Experiment Station, Tucson). Is drip 1972 irrigation for Arizona. Progressive Agriculture in Arizona, Vol. 24, No. 8, pp. 6-7, May-June 1972.

Decreasing availability and rising labor and water costs are causing growers to consider replacing surface irrigation by drip systems. Drip systems deliver water to the vicinity of a plant where discharge is controlled by an emitter. Systems consist of a pump, filters, meter, control valves, pipe and emitters. Fruit trees are best suited to drip systems as extensive pipe networks are required. Drip irrigation provides better water control where only the actual root-soil volume is watered. Additional water may be required to remove accumulated salts. Systems cost from $150 to $500 per acre and are economical for high value crops. Tailwater runoff is eliminated. A 95% water savings occurred on young trees compared to adjacent surface irrigated trees. Water savings from 20 to 50 percent on mature trees are estimated. Consumptive use requirements, labor savings, emitter designs and irrigation equipment are discussed. Drip systems are useful in Arizona where there are high value crops, high water and labor costs, limited water supply, available capital, and a willingness to overcome uncertainties involved.

Gustafson, C. D. (University of California, San Diego). History of drip
1973 irrigation. Irrigation Age, Vol. 7, No. 11, pp. 4-6, June, 1973.

Drip irrigation's history from the first research in Israel to later studies in the United States, Italy, Japan, Australia, and Mexico is reviewed. New methods along with a forecast for the future are outlined.

Hutto, H., Jr. Drip country, U.S.A. Irrigation Age, Vol. 7, No. 11, pp. 32-35,
1973 June 1973

A pictorial tour is presented of drip irrigation country, systems, crops, types of emitters, hardware, and techniques peculiar to this type of irrigation.

Milne, J. Trickle irrigation in Australia. Irrigation Journal, Vol. 23,
1973 No. 6, p. 21, Nov.-Dec. 1973.

A brief history of trickle irrigation in Australia is given. The use of irrigation scheduling in the operation of the trickle system is also noted.

Willardson, L. S. (Agricultural Research Service, Brawley, California,
1972 Imperial Valley Conservation Research Center). Attainable irrigation efficiencies. Journal of Irrigation and Drainage Division, American Society of Civil Engineers, Vol. 98, No. IR2, Pp. 239-246, June 1972.

The general objective of irrigation is to provide a suitable moisture environment in the soil for plant growth. Since water supplies for irrigation in the arid and semiarid western U.S. have never been as plentiful as irrigators would like, the concept of irrigation efficiency has received much attention. Irrigation efficiency is considered equivalent to water application efficiency or the percentage of water applied that is actually stored in the root zone for use by the crops. Water application efficiency is critically determined by uniformity of field water application in amounts that will not exceed root zone storage capacity. Such uniformity is difficult to attain in surface irrigation if light irrigations are required, if soil infiltration rates are high or if soil intake characteristics vary spatially. Physical, economic and political factors affecting water application efficiency are discussed. Application uniformities of different irrigation systems are discussed. The coefficient of uniformity of sprinkler systems vary widely depending on characteristics of the sprinkler system and the water distribution pattern. Trickle systems look promising but uniformity data are not yet available.

Woudt, B. D. Van't. (Food and Agriculture Organization of the United Nations, Bangkok, Thailand). Trickle irrigation--a promising second tool for a breakthrough in food production in tropical, subtropical and desert areas. International Commission on Irrigation and Drainage Bulletin, pp. 88-96, July 1968.
1968

A method developed in Israel through which a water-fertilizer mix is continuously dripped on the soil at the base of a crop plant under field conditions is discussed. Noncorrosive plastic tubes are placed on the ground next to the base of crop plants. No soil levelling is required. The tubes, which can be permanent installations, continually drip water-fertilizer mix to plant roots. Control head units with water tap and filter, water meter, and fertilizer tank are located about every five acres. The unit requires about 2.5 ga/hr and the system takes 1 to 2.3 ATM of pressure. Early results, conclusions from related work, and field observations show that this method may produce high yields, allow water of high salinity to be used, reduce drainage problems, and permit complete automation under field conditions in such a way that water and fertilizer applications meet but not exceed plant needs. Although the cost of installation varies from $1000 to $3000/ha, results may pay for this investment within a short time.

B. Physics and Mathematical Models

Bernal, R. (North Carolina State University, Raleigh, Department of Biological and Agricultural Engineering). Movement of water through fine sandy loam soil under subirrigation and drainage conditions. M.S. Thesis, N. C. State Univ., Raleigh, 1971.
1971

Analysis of water movement through soil is important to design criteria for irrigation and drainage, particularly under nonsteady or time-variable flow. Saturated and unsaturated flow were investigated under these conditions by field and laboratory determinations of hydraulic conductivity as a soil-water content function for a wide range of conditions. Water-table movement, responding to subirrigation and drainage, was measured and compared to numerical calculations. Theoretical solutions and observed field data were compared by four selected drain-spacing equations. Two solutions gave good predictions using field-determined conductivity. The field determination of conductivity proceed reliable. Hydraulic conductivity varied largely with depth. Figures include comparisons of observed and calculated water-table rise, cumulative infiltration curve, and hydraulic conductivity versus soil-water content.

Brandt, A., E. Bresler, N. Diner, I. Ben-Asher, and J. Heller. (Weizmann Inst. of Science, Rehovoth, Israel, Department of Applied Mathematics). Infiltration from a trickle source, I. Mathematical models. Soil Science Society of America Proceedings, Vol. 35, No. 5, pp. 675-682, Sept.-Oct. 1971.
1971

Theoretical considerations were used to develop mathematical tools to analyze multi-dimensional transient infiltration from a trickle source. Two mathematical models considered are a plane flow model and a cylindrical flow model. The diffusion type water flow equation in unsaturated soil was solved numerically by an approach that combines the noniterative ADI differences procedure with Newton's iterative method. The method is reliable and can be used with confidence. Typical results demonstrate the effects of trickle discharge on the water content field, the saturated water entry zone, and the water flux at the soil surface.

Bresler, E., J. Heller, N. Diner, I. Ben-Asher, and A. Brandt. (Volcani
1971 Inst. of Agricultural Research, Bet-Dagan, Israel). Infiltration from a trickle source, II. Experimental data and theoretical predictions. Soil Science Society of America Proceedings, Vol. 35, No. 5, pp. 683-689, Sept.-Oct., 1971.

The theory of transient infiltration from a trickle source was compared with experimental results. The agreement between theory and experiment is generally good and suggests that the theory is applicable to many field situations. The theory, as well as the experimental data, indicate that for the conditions studied, an increase in the trickle discharge more prominent when the trickle discharge is small, whereas, lack of precision in estimating the soil-water parameters is more crucial when the discharge is large.

Bucks, D. A. and L. E. Myers. (Agricultural Research Service, Phoenix, Arizona,
1973 Water Conservation Laboratory). Trickle irrigation--application uniformity from simple emitters. Transactions of the ASAE (American Society of Agricultural Engineers), Vol. 16, No. 6, pp. 1108-1111, Nov.-Dec., 1973.

Procedures for design and construction of two multiple-size systems, using a stainless-steel and microtube or spaghetti-tube emitter, were developed. Mean discharge deviations for these simple emitters operated at constant pressure were from 1.7 percent to 3.3 percent for the stainless-steel emitters, and from 1.8 percent to 2.5 percent for the microtube emitters. Performance by a multiple-diameter stainless-steel emitter system designed for row-crop usage verified the practicality of changing emitter diameters along the lateral. The theoretical performance of a 250-foot lateral with a 2-foot emitter spacing, using five sizes of stainless steel emitters, showed a mean deviation of 1.7 percent and maximum deviations of +5.2 percent to -6.6 percent from design discharge. Actual mean deviation from design discharge was 3.1 percent, with maximum deviations of +8.8 percent to -10.8 percent in the field.

Cho, T., T. Yamamoto, and S. Watanabe. (Tottori University, Japan, Sand Dune
1973 Research Institute). On the hydraulics of the nozzle on trickle irrigation system (in Japanese). Bulletin No. 12, pp. 13-19, March 1973. (English Summary)

Trickle irrigation, developed in recent years in such arid agricultural areas as Australia, Israel, and the United States, features water under pressure distributed by a series of nozzles near the crop root zone. Here pressure is dissipated, and water drips out at a relatively slow rate. Nozzles, made of polyethylene materials, were trial-manufactured, and hydraulic experiments to demonstrate the effectiveness of the various sizes were conducted. Relationships between pressure and discharge rates of the nozzles were determined by making use of White's empirical formula for the friction factor of laminar flow in curved pipes. It is felt that these determinations can be applied in the design and manufacture of such nozzles for practical use.

Gilley, J. R. and E. R. Allred. (Minnesota University, St. Paul, Department of Agricultural Engineering, St. Paul). Infiltration and root extraction from subsurface irrigation laterals. Paper No. 72-743, presented at winter meeting of the American Society of Agricultural Engineers, Dec. 11-15, 1972.
1972

An analytical solution to the soil moisture flow equation was used to simulate flow in partially saturated soils during steady infiltration from buried line sources. A series of plane sinks was used to model water consumption by plants. The resulting model was used to determine optimum lateral placement to obtain desired crop extraction patterns.

Goldberg, S. D., M. Rinot, and N. Karu. (Hebrew University, Jerusalem, Israel, Dept. of Irrigation and Ministry of Agriculture, Rehovoth, Israel). Effect of trickle irrigation intervals on distribution and utilization of soil moisture in a vineyard. Soil Science Society of America Proceedings, Vol. 35, No. 1, pp. 127-130, Jan.-Feb. 1971.
1971

In an established vineyard on sandy clay soil the effect of trickle irrigation interval on soil moisture and salt distribution and relative water use efficiency was examined. The distribution of soil moisture and salinity resulting from this irrigation method is two dimensional, with moisture contents high along and beneath the row and decreasing laterally. The main active soil layer supplying water to the roots was found to be restricted to a strip approximately 2 m wide and 120 cm deep beneath the rows, whereas the total distance between rows was 3 m. The effect of shorter irrigation intervals, with proportionally smaller amounts of water applied in a single irrigation, was to decrease the variations of moisture content in the root zone and establish a continuously higher moisture regime. Salts were concentrated in a surface pocket and a deep layer with a leached zone between them. The relative position of the concentration layers was determined by the amount of water applied in a single irrigation. Relative water use efficiency was postively affected by shorter irrigation intervals both in terms of grape production and weight of prunings.

Halsey, D. 1972 (University of California, Riverside, Citrus Research Center and Agricultural Exp. Station). Water, salt patterns with desert drip irrigation. Citrograph, Vol. 57, No. 4, pp. 147-148, Feb. 1972

The movement of water and salt in an undisturbed desert soil is reported with reference to dripper irrigation of lemons near Mecca, California. New lemon trees were irrigated individually by one two-gallon/hour drippers using water with electrical conductivity of 1.9 millimhos. The coachella soil has an 18 inch loamy fine sand surface overlaying a fine sand without structure or cementation. After two months of irrigation and normal and healthy root growth, trenches were dug to observe the wetted profile under the last dripper on a line. Soil samples were taken at one-foot intervals vertically and horizontally, and conductivity of the saturation extract was measured. Lateral water movement extended 11.5 feet from the dripper. Vertical penetration was deepest directly under the dripper at 4.5 feet. Salt was concentrated at extreme lateral points, largely as a result of surface evaporation. A mulch is suggested to reduce the salt concentration in lateral extremities.

Myers, L. E. and D. A. Bucks. 1972 (Agricultural Research Service, Phoenix, Arizona, Water Conservation Laboratory). Uniform irrigation with low-pressure trickle systems. Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, Vol. 98, No. IR3, pp. 341-346, Sept., 1972.

Application uniformity from low-pressure trickle irrigation systems can be greatly improved by varying emitter sizes to compensate for friction-induced pressure changes in the lateral pipe. Low-pressure systems using simple emitter sizes suffer from nonuniform emitter because friction-induced pressure changes are a large percentage of total pressure high-pressure trickle systems alleviate this problem by using high head emitters. Low-pressure systems, using simple emitters, can have several advantages over high-pressure systems in reduced manufacturing and operating costs, larger orifices to reduce clogging, and simpler flow control devices. Comparable application uniformity can be obtained by varying emitter sizes in the low-pressure systems. Procedures for designing low-pressure multiple-emitter size trickle systems by computer or by a simplified computations and graphic method were developed.

Philip, J. R. 1971 (Commonwealth Scientific and Industrial Research Organization, Canberra, Australia, Division of Environmental Mechanics). General theorem on steady infiltration from surface sources, with application to point and line sources. Soil Science Society of America Proceedings, Vol. 35, No. 6, pp. 857-871, Nov.-Dec. 1971.

A general theorem enables the solution of the quasilinearized steady infiltration equation for any distribution of surface sources to be found immediately from the corresponding (mathematically simpler) solution for buried sources. It is introduced through the special cases of the surface line and point sources. These solutions hold also for steady infiltration from furrow and basins. Corollary to the general theorem, relations of the same type hold between the horizontal flux density components. Both the theorems and the special results apply also to processes such as diffusion in a uniform convective flow and sedimentation under gravity and Brownian motion.

Philip, J. R. (Commonwealth Scientific and Industrial Research Organization, Canberra, Australia, Division of Environmental Mechanics). Steady infiltration from buried, surface, and perched point and line sources in heterogeneous soils, I. Analysis. Soil Science Society of America Proceedings, Vol. 36, No. 2, pp. 268-273, March-April 1972.
1972

The quasilinearized steady infiltration equation is generalized to apply to heterogeneous soils with conductivity depending exponentially on both moisture potential and depth. Mathematical developments, including a theorem connecting surface and buried source solutions. Follow closely those established previously for homogeneous soils. Solutions are found for buried, surface, and perched point and line sources. Physically relevant solutions are limited to the following ranges of the dimensionless coefficient of dependence of conductivity on depth, for buried and surface sources, zero or larger; for perched point sources, -1 or smaller; for perched line sources, -1. The homogeneous medium with the zero coefficient is an extreme case for existence of buried and surface source solutions. Perched source solutions (relevant to subirrigation) exist only for soils with conductivity increasing rapidly with height above the impermeable base.

Raats, P. A. C. (Johns Hopkins University, Baltimore, Maryland). Steady infiltration from point sources, cavities, and basins. Soil Science Society of America Proceedings, Vol. 35, No. 5, pp. 689-694, September-October 1971.
1971

Steady infiltration from buried point sources and surface point sources is analyzed using partial differential equations for the matric flux potential and the stokes' stream function associated with axially symmetric flows. Hydraulic conductivity is assumed to be an exponential function of the pressure head. Explicit expressions were obtained for the matric flux potential, the stokes' stream function, the flux, the pressure head, and the total head. Related upward flows for which the soil becomes saturated everywhere are discussed briefly. Comparison of the solutions for buried point sources, surface point sources, and gravity-free flows shows how the gravitational force and the geometry interact in determining the nature of the flows. The solutions are of interest in planning systems of trickle irrigation.

Skaggs, R. W. 1972 (North Carolina State University, Raleigh, Department of Biological and Agricultural Engineering). Water table control with subsurface irrigation. Paper No. NA72-205 presented at 1972 annual meeting--North Atlantic Region, American Society of Agricultural Engineers, University of Maryland, College Park, Maryland, August 13-15, 1972.

Field experiments were conducted to characterize soil-water movement during subirrigation on a Lumbee sandy loam soil. Results for the water table response to subirrigation are presented and compared to predictions from theoretical approaches. Solutions were presented for the water table response to subirrigation for both initially draining and horizontal profiles. Numerical procedures were used to solve a nonlinear differential equation for saturated soil-water movement. A solution to the linearized equation was also presented and compared to the numerical results. The results of experiments showed that water could be supplied to the root zone at a rate more sufficient to satisfy plant needs for 7.5 and 15 m tile spacings. However, the response was too slow for the 30 m tile lines. Theoretical calculations showed that the suggested water talbe depth range of 60 to 90 cm could be maintained in this soil with a tile spacing of 19.1 m.

Spomer, L. A. 1972 (Illinois University, Urbana, Department of Plant Physiology and Horticulture). Saturated water flow through clay pots. Soil Science Society of America Proceedings, Vol. 36, No. 6, pp. 976-978, 1972.

An electrolytic tank electric analog was used to simulate saturated water flow through standard clay pots during both flood and drip irrigation. Simulated flow patterns indicated significant zones of low flow rates, particularly during drip irrigation.

Van Bavel, C. H. M., J. Ahmed, S. I. Bhuiyan, and E. A. Hiler. 1973 (Texas A&M University, College Station, Department of Soil and Crop Sciences). Dynamic simulation of automated subsurface irrigation systems. Transactions of the ASAE (American Society of Agricultural Engineers), Vol. 16, No. 6, pp. 1095-1099, Nov.-Dec. 1973.

Water delivery and distributions from a subsurface irrigation system were simulated for a simplified one-dimensional case. Water loss by surface evaporation and root uptake was taken into account in a manner reflecting its dependence upon depth and time of day. The system was defined as an automatic one, in which the water content at a given depth would turn infiltration from the buried delivery system off and on. The simulation was performed in S/360 CSMP, a dymatic simulation language that appears well adapted for this type of problem. The program

is efficient and allows ready substitution of the hydraulic distribution with depth, as well as geometrical variables. The results that in a Yold clay loam and with a typical consumptive use and root period of about 40 hours. While maintaining an essentially constant water content in the root zone, provided the depth of delivery and control are properly chosen.

Warrick, A. W. 1974 (Arizona University, Tucson, Department of Soils, Water Engineering). Time-dependent linearized infiltration: I. Point sources. Soil Science Society of America Proceedings, Vol. 38, No. 3, pp. 383-386, May-June 1974.

Soil water flow from a point source was analyzed using a linearized form of the moisture flow equation. Time-dependence was assumed with the results simplifying to those for steady-state conditions. Discrete time-distributed inputs such as for trickle or high frequency irrigation are amenable to solution. Numerical simulations include the advance of a wetting front during infiltration, moisture variation resulting from a cyclic input as during irrigation, and the matric flux potential field for a two-source problem.

Zachmann, D. W. and A. W. Tomas. 1973 (Colorado State University, Fort Collins, Department of Mathematics). A mathematical investigation of steady infiltration from line sources. Soil Science Society of America Proceedings, Vol. 37, No. 4, pp. 495-500, July-Aug. 1973.

Equations which can be used in the design of subsurface irrigation systems are based on the physics of steady infiltration from a distribution of line sources which lie in a horizontal plane and areparallel and equally spaced. The analytical solution describes the flow from the line sources in the presence of uniform infiltration or evaporation at the soil surface. To increase the utility of the solution, the equations for matric flux potential and stream function are written in dimensionless form.

C. Management and Mechanics

Cho, T. and T. Yamamoto. 1973 (Tottoire University, Japan, Sand Dune Research Institute). On application efficiency and effects of trickle irrigation in a sand dune field. (In Japanese) Bulletin No. 12, pp. 20-28, March 1973 (Summary in English).

In arid agricultural regions characterized by low water resources and high evaporation rates trickle irrigation has many advantages since high irrigation efficiency is essential. Experiments testing trickle irrigation application efficiency were conducted

using small lysimeters in open fields and in a plastic greenhouse. Compared with sprinkler irrigation, trickle irrigation was found to (1) hold the soil moisture content in the root zone of all crops higher than field capacity--7.4% by volume--during the day, (2) afford an application efficiency of 9-39% higher, (3) give crops yields of 19-25% higher in the open fields and 14-68% higher in the plastic greenhouse.

Davis, Sterling, and Sheldon D. Nelson. (University of California, Riverside, 1970 Agricultural Research Service). Subsurface irrigation easily automated. ASCE Proceedings, Journal of the Irrigation and Drainage Division, Vol. 96, No. 1R1, Paper 7135, pp. 47-51, March 1970.

Subsurface irrigation applies water directly into the root zone of the crop and may easily be automated. Two subsurface irrigation systems are described, an automatic float-operated device to supply water needed to a tree or plants, and a plastic hose with inserts, planted with the potato seed and picked up with the mature potatoes.

Deremer, E. D. (Agronomics, Inc., Avondale, Arizona). A simple method 1972 of drip irrigation. Irrigation Journal, Vol. 22, No. 3, pp. 10-15, May-June 1972.

The method of irrigation by drip or trickle systems (flow rates of less than 5 gal/hr) is well established in the U.S., Israel, Australia, and Mexico. In Arizona, these systems have enabled commercial operators to realize water savings of from 50 percent (in vegetables) to 95 percent in some tree installations. A simple method for determining the amount of irrigation water to use for a particular crop is discussed. Formulas and their use in determing the amount of water to apply each day, week, or other time period, are presented. Drip irrigation minimizes water losses, and tensiometers measure soil moisture, indicating the time and amount of irrigation required. This type of system is proving to be the ultimate in irrigation water conservation.

Fok, Yu-Si and L. S. Willardson. (Hawaii University, Honolulu, Department 1971 of Civil Engineering). Subsurface irrigation system analysis and design. Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, Vol. 97, No. IR3, pp. 449-454, 1971.

By considering the phenomenon of subsurface irrigation as a case of two-dimensional infiltration, a method is developed for analyzing the water distribution pattern in the soil profile from a subirrigation pipe placed on a barrier. Equations of

soil-water movement were used to establish the design criteria of the discharge, the burial depth and the spacing of the subsurface irrigation system. A numerical example is given to show the procedures of the proposed method for subsurface irrigation system analysis and design.

Goldberg, D. and M. Shmueli. Drip irrigation--a method used under arid
1970 and desert conditions of high water and soil salinity. American Society of Agricultural Engineers, Transactions, Vol. 13, No. 1, pp. 38-41, January-February 1970.

Drip irrigation has many advantages over other forms of irrigation when used in arid regions characterized by saline soil, saline irrigation water, and high evapotranspiration rates. It shortens growing seasons, produces earlier crops, increases crop yield, and makes it possible to grow crops which would normally be salt-damaged. A summary of experimental soil problems as they relate to the drip irrigation method are discussed.

Hammond, R. P. and J. W. Michel. Irrigation system. (Available from the
1972 National Technical Information Service as Pat Appl.-228 676 (70), $3 in paper copy, $1.45 in microfiche, Atomic Energy Commission Patent Application Serial Number 228, 676 (70), February 1972.)

Subsurface and trickle irrigation techniques have received attention in recent years as potential methods for increasing irrigation efficiency in the agriculture of arid lands. A spring mechanism is used on slits in plastic distribution pipe to control the size of the aperture at operating water pressures. Such a spring assures the opening of the slit at a given pressure and also increases the closing pressure. A detailed description of the system is presented as are several preferred embodiments. The system tends to make all the slits operate simultaneously in response to pressure pulses, which also clean the slits of debris. The length of pipe in each system may be increased due to the higher operating pressure, and gaseous fertilization may be introduced through the system. The system is economical in that it may be installed mechanically at low cost and it employs a smaller amount of irrigation water than other methods.

Hoskyn, John P. and Billy B. Bryan. (Arkansas University, Fayetteville,
1969 Department of Agricultural Engineering) Subsurface irrigation research in Arkansas. (Available from the Clearinghouse as PB-189 081, $3 in paper copy, 65¢ in microfiche, Water Resources Research Center, Publication No. 3, Arkansas University Experiment Station Report Series 179, June, 1969.)

Subsurface irrigation of cotton was studied to determine and evaluate the hydraulic problems in distributing water in small-

diameter perforated plastic pipe at low pressures and to develop optimum design criteria. A greenhouse study of a subirrigation system indicated that 2 psi should be considered as a lower-limit pressure when orifices are built into the pipe wall. A placement depth of 12 inches was preferable to 18 inches in terms of the amount of water required. Twelve inches was used as the depth of placement for a field subirrigation system. From the standpoint of seasonal soil moisture levels and from observations of the system in operation, the following conclusions are drawn, (1) a pressure head of 6 feet of water is preferable to 10 feet, (2) 38-inch lateral spacing is preferred over 76-inch spacing, and (3) an orifice spacing of 30 inches is preferable to a spacing of either 12 or 49 inches. Internal plugging of orifices because of poor quality water was evident. A sufficient selection of valves, timers, engine motor controllers, etc., is already commercially available.

Howell, T. A. and E. A. Hiler. (Texas A&M University, College Station).
1972 Trickle irrigation system design. Paper 72-221, 1972 Annual Meeting of American Society of Agricultural Engineers, Hot Springs, Arkansas, June 1972.

Trickle irrigation is the slow application of water to plants in the form of drops through mechanical emitters, offering great potential to areas with limited or costly water. System pressure losses are very small. A design procedure is presented for trickle laterals with nonuniformly spaced emitters in an orchard installation. Lateral design determines optimum pipe size and number of emitters per tree, neglecting runoff. Real consumptive use rate depends on type of crop and climate. A Fortran V program accounted for pressure drop, emitter flow ratio, total lateral flow, tree spacing, number of emitters per tree, emitter spacing, pressure at lateral end, field slope, and lateral length. A program flow chart is presented. Design procedure is given in 7 steps, and lateral design examples provided. The proposed method may lead to over design, requiring application of practical experience. Experimental verification of pressure distribution predicted by the computer has not been conducted.

Kenworthy, A. L. (Michigan State University, East Lansing, Dept. of
1972 Horticulture). Trickle irrigation surges ahead. American Fruit Grower, Vol. 92, No. 4, pp. 15-17, 34 April 1972.

Trickle, drip or daily flow irrigation prevents moisture stress by maintaining favorable soil moisture conditions on at least

a portion of the root system. Water is applied at low pressure (15 Psi) at slow rates (1 to 2 GPH) to maintain a part of the soil at or near field capacity, and soil moisture measurements then can be used to indicate whether adequate water has been applied. Orchards may be irrigated this way, and each 10 GPM well may irrigate 6 acres. Technical details are presented concerning the installation of trickle irrigation systems. Experiences in San Diego County, Israel, and East Lansing, Michigan, are outlined. Trees respond to trickle irrigation as if they received extra nitrogen. An installation cost of $50 to $100 per acre is practical.

Kriz, G. J. 1971 (North Carolina State University, Raleigh). Drain and irrigate with the same system. World Farming, Vol. 13, No. 11, p. 30, November 1971.

A summary review is presented of some implications of a field study to determine the feasibility of combined subirrigation-drainage systems on soils with shallow natural water tables. Benefits of the combined system are cited. This system is applicable to situations with a high water table or impermeable layer located 3-7 feet below the soil surface.

Lyons, C. G., Jr. 1972 (Texas A&M University, Weslaco, Agricultural Research and Extension Center). Trickle irrigation...A more efficient means of water management. Texas Agricultural Progress, Vol. 18, No. 1, pp. 2-4, Winter, 1972.

The sudden increase in the use of trickle irrigation is attributed to the availability of low cost plastic pipe and the shortage of water in some areas. Trickle irrigation is the application of water, on a regular basis, directly to the plants root zone. A trickle system consists of a water source, pump, filter, time clock, pressure regulator, mainline, laterals, and emitters. Costs for the system vary from $150 to $500 per acre. Advantages of the method include water and labor savings, increased yield, and ability to use lower quality water. Disadvantages include system malfunction, salt accumulation, disease factors, and cost.

McConnell, G. E. 1971 Let your irrigation system do all the work. American Fruit Grower, Vol. 91, No. 5, May 1971, pp. 16-18.

An integrated underground irrigation system can be used to irrigate, protect crops from frost, and apply pesticides and fertilizers. Design and construction of a permanent watering system are

presented. Triangular spacing of sprinklers gave the best coverage. The system is feasible for any intensively used land whose irrigation is economical. The installed cost of the underground system was less than half the cost of a traditional portable aluminum pipe system. Water well pumps were selected because of flat performance curves. A commercial air compressor cleans all laterals easily. Different chemicals and fertilizers have been applied by this system which also reduces frost hazard. (Sprinkler irrigation)

New, L. 1973 Drip irrigation, Texas style. Irrigation Age, Vol. 7, No. 11, pp. 19-21, 23 June 1973.

Drip irrigated field tests on West Texas Orchards, South Plains Greenhouses and Dawson County row crops have recently been initiated. Preliminary results of these tests are most favorable and Texas farmers seem pleased at the prospect of this relatively new form of irrigation.

Osborn, R. O. and D. G. Boyle. (Boyle and Osborn, Lockport, New York). 1974 Irrigation system. Official Gazette of the U. S. Patent Office, Vol. 925, No. 3, p. 788.

An irrigation system employs a novel flexible tubing for the distribution of water, particularly in a subsurface irrigation system. The tubing, having at least a portion of the surface composed of a permeable, fibrous material through which water may pass at a slow, controlled rate with a negligible pressure drop through the system, is inexpensive to manufacture and install and is capable of confining the delivered water to the desired areas only. The tubing is characterized as a tubular body formed by joining together along their longitudinal edges only, a plurality of elongated flexible strips of plastic or other suitable material. At least one of the strips is composed of a permeable, fibrous material, preferably a non-woven fabric, capable of slowly passing a liquid, such as water, or a gas. Another of the strips may be solid and impervious or may be formed of the same or a different permeable, fibrous material.

Whitney, Lester F. (Massachusetts University, Amherst). 1968 Subsurface irrigation of turf areas, nozzle design and spacing. Project Completion Report, January 1968.

Subsurface irrigation of crops and turf areas can permit up to a 40% reduction in water usage, provide automatic irrigation, and permit introduction of liquid chemicals into the root zone. The main deterrent to widespread adoption of this method has been the absence of an orifice which resists internal and

external clogging. One which approaches the longevity of the polyethylene plastic pipe lateral system. Results from this work have culminated with an injection-molded plastic insert nozzle which pierces the plastic pipe wall such that the inlet to a sized orifice is at the point of maximum velocity within the pipe. A labyrinthian protection for the orifice prevents external clogging. All in-wall orifices have been found to be unequivocally nonuniform and short lived. Spacing of orifices have been related to soil profiles and soil types for which flow parameters have been established. The findings are significant in providing a designed orifice for subsurface irrigation with maximum protection against internal and external clogging leading to a longevity approaching that of the base pipe material.

Wilke, O. 1973 (Texas A&M University, Lubbock, Agricultural Research and Extension Center). Improved installation of microtube drip irrigation emitters. Agricultural Engineering, Vol. 54, No. 5, p. 17, May 1973.

Microtubes as drip irrigation emitters have several distinct advantages--low cost, good hydraulic characteristics, ease of installation. But if the wall of the microtube is thin, the tube may be pinched partially or totally closed where the tube is inserted into a hole punched in the irrigation lateral pipe. If the microtube is extended from the irrigation pipe, it may be cut by rabbits. As microtube emitter flows are increased, the water stream may travel several feet from the emitter. Foliage may be wetted. As the plastic irrigation pipe twists due to contraction, the stream direction may change, altering the soil area wetted by the emitter. These problems can be eliminated at negligible cost by sliding a short piece of black polyethylene tubing over the outlet end of the microtube.

Wilke, O. C. and C. W. Wendt. 1971 (Texas A&M University, Lubbock, Agricultural Research and Extension Center). Performance of a twin-wall trickle irrigation hose. 1971.

A twin-wall trickle irrigation hose was tested from May through October on various plants, including grapes and cabbages. The hose was formed from black polyethylene sheets which were cut into strips, perforated, and heat welded. The outer layer orifice spacing was 18 in while inner-wall orifice spacings were 72 and 144 in. Average flow rates and flow variability was examined, and increasing pressure from 3 to 15 Psi was found to decrease flow variability. Maintenance was minimal,

and could be further decreased by strengthening the heat weld. Trickle irrigated and furrow irrigated plots of cabbage were studied. The trickle irrigated rows required 40% less water to maintain root zone soil moisture tension at or below 30 centibars. In addition, furrow irrigation concentrated salts in the top inch of the irrigated soil, while trickle irrigation moved salts from the beds to the furrows, a characteristic which should improve plant germination where salinity is a problem.

D. Water Use, Salinity, and Fertilization

Anonymous. 1973. Winery's drip irrigation system high successful. Ground Water Age, Vol. 7, No. 5, pp. 26-29, January 1973.

A drip irrigation system has been installed at the Buena Vista Winery near Sonoma, California. Over 192 miles of tubing provide 145,000 vines with individual irrigation emitting one gallon of water per hour at the base of each vine. Irrigation is almost daily to insure constant wetness for the root zone of the vine. Surface run-off is eliminated, evaporation losses are minimal, and no water is wasted on weeds between the rows. Since rows between vines remain dry, concurrent cultivation is possible, drip irrigation emitters provide all vines with a completely uniform water supply regardless of elevation or location in the vineyard. Water filtration is highly critical as emitters otherwise become clogged. The filtering system forces water through three concentric ring elements which decrease successively in mesh size. Thirty tensiometers are located throughout the vineyard to determine drip irrigation schedules. About eight gallons of water per vine per season are used. There is some salt buildup since this water is applied directly at the base of the vine, rather than across the entire field as with overhead sprinkler systems. However, with a normal fifteen inches of rainfall, this salt is leached out. Far less water has been used than was originally anticipated, serving to conserve irrigation water which is entirely supplied by a catch basin reservoir.

Bernstein, L. and L. E. Francois. (Agricultural Research Service, Riverside, California Salinity Laboratory). Comparisons of drip, furrow, and sprinkler irrigation. Soil Science, Vol. 115, No. 1, pp. 73-86, 1973.
1973

Studies were initiated in 1970 to determine the relative merits of drip, furrow, and sprinkler irrigation methods with respect to yield potential, salinity hazards, and efficiency of water use. The bell pepper (Capsicum frutescens var. Oakview Wonder) was chosen as the experimental plant. When the same amount of low-salinity water (450 mg/l total salts) was applied by the three methods of irrigation in a first experiment. The drip-irrigated plots out-yielded the furrow- and sprinkler-irrigated ones by about 50 percent. Brackish irrigation water (2450 mg/l total salts) caused only a 14 percent reduction in yield with drip irrigation but 54 and 94 percent reductions in yield for furrow- and sprinkler-irrigated plots, respectively. When irrigation frequency was increased for furrow and sprinkler treatments in a second experiment, yield differences decreased markedly, virtually disappearing with the low-salinity water, while the brackish water caused 18 to 59 percent yield reductions for the furrow- and sprinkler-irrigated plots, respectively. Drip irrigation required about one-third less water than furrow irrigation for maximum yield of the annual bell pepper crop. The saving of water occurred while the crop was young. For mature crops, water requirements by the three methods of irrigation are similar.

Chuprin, I. A. and N. F. Lobov. Use of local water resources for irrigation (Orosheniye Mesinymi Vodnymi Resursami). Rossel' Khozizdat, Moscow, 1970. 128 p.
1970

This publication on irrigation was compiled on the basis of recent advances made in the application of local water resources to agricultural lands in the southern part of European Russia. The book provides information on the construction and operation of irrigation systems and describes modern crop-irrigation practices in different geomorphological and land reclamation zones. Local water resources in dry eastern regions of the northern Caucasus and Volga River are examined in terms of the use of these waters for irrigation by Kolkhozes and Sovkhozes of the area.

Cunha, F. R. 1970 (Mozambique University, Lourenco Marques, Department of Agronomy). Trickle Irrigation ("Rega Goticular"--in French). Rev. Cienc. Agron. Ser. B., Vol. 3, No. 1, pp. 15-28, 1970.

The principles and objectives of the trickle or drip irrigation applied for the first time in Israel are presented. The essential infra-structures of the method and some trials carried out both in Israel and Australia are described as well as some commercial applications. It advantages over the furrow, sprinkler and flood irrigations in poor, coarse and salty soils are pointed out. Emphasis is put on plant water requirements by the use of the trickle irrigation through the studies of water circulation in the soil-plant-atmosphere system. The application of this new irrigation system in Mozambique is suggested.

Deremer, E. D. 1970 New findings on the use of trickle irrigation systems in the United States, Australia and Israel. World Irrigation, Vol. 20, No. 6, pp. 14-16, December 1970.

Trickle irrigation has been receiving much publicity and attention throughout the world. Several workers, independent of each other, are reporting phenomenol water savings and sizable yield increases. Studies in Israel show increases of 50 to 100 percent with trickle irrigation as compared to sprinkler or furrow irrigation for tomatoes, cucumbers, melons, peppers, and sweet corn. Trickle irrigation was used on a 10-acre plot of lemons near Yuma, Arizona, with the following results. Water use was 1/9th, irrigation labor cost was 1/16th. Cultivation was reduced by 60 percent. Fertilizer use was 20 percent, and yield was more than double. Another benefit of trickle irrigation is that poorer quality water can be used with no apparent damage to the area.

Ekern, P. C. 1972 (Hawaii University, Honolulu, Water Resources Research Center). Use of water by sugarcane in Hawaii measured by hydraulic lysimeters. In Proceedings of 14th Congress, International Society of Sugarcane Technologists, 1972, pp. 805-812.

Consumption of water by sprinkler and drip irrigated sugarcane was measured in Hawaii by hydraulic load cell lysimeters. One-eye cane transplants of variety H 50-7209 were set in a 5 x 5 ft grid under flat bed culture in Molokai Latosol. Water use by full canopy sprinkler irrigated approximated that from a conventional class A pan. The water use often equalled or exceeded full net radiation for both pan evaporation and cane evapotranspiration,

indicative of positive advection of heat. The fraction of sunlight coverted into net radiation had a strong seasonal change from 0.53 in summer to 0.38 in winter for cane and from 0.63 in summer to 0.47 in winter for pan. The patterns of water use closely reflected this seasonal change in net radiation.

Falk, D. C. 1970 Salt water irrigation system. U. S. Patent No. 3, 528, 251, Official Gazette of the U.S. Patent Office, Vol. 878, No. 3, p. 581, September 15, 1970.

This invention provides a subsurface trough-like structure at a depth about equal to the root system of the crop to be grown. A barrier above the water surface prevents entry of soil into the trough but permits water vapor to move out of the trough into the adjacent soil. Since there is direct contact between the liquid water and the soil, there is no tendency for the water to soak into and poison the soil. The trough may be a pipe having perforated walls well above the level of the salt water.

Goldberg, D., B. Gornat, M. Shmueli and I. Ben-Asher. (Hebrew University, Rehovoth, Israel, Department of Irrigation). 1971 Increasing the agricultural use of saline water by means of trickle irrigation. Water Resources Bulletin, Vol. 7, No. 4, pp. 802-809, August 1971.

A study was conducted in two arid zones in Israel to determine the effect of saline water applied to various crops growing in coarse-textured soil. Using trickle irrigation the test crops responded favorably in terms of plant development and yield. The method provides the possibility of raising the permissible salinity level of irrigation water and thus to increase the water reserves suitable for agricultural use in the world. The experiments were conducted in two arid regions with saline water sources. The first is the Arava near the Gulf of Aquaba, and the second is the El-Arish district in the northern part of the Sinai Desert. In gneral, the Arava soils are finer textured and more saline than those at El-Arish. The water contains more sulphates, and the climate is very hot and dry. In the El-Arish district, the soil is very sandy, and its salinity is low. However, the water is highly saline, and the chlorine content is also high. The yield from trickling in the Arava was double that obtained by sprinkling, and at El-Arish it was 70% greater. For tomatoes in the Arava, the yield by trickling was 66% greater than that achieved by sprinkling, and at El-Arish it was 161% greater.

Goldberg, D. and M. Shmueli. (Hebrew University, Jerusalem, Israel, 1971 Department of Irrigation). The effect of distance from the tricklers on soil salinity and growth and yield of sweet corn in an arid zone. Hortscience, 6(6 Sec. 1), pp. 565-567, 1971.

The effect of the distance between crop row and tricklers on growth and yield of sweet corn, and on soil moisture and salinity was studied. The maximum yield was obtained when the nozzles were located 5-25 cm from the plants. Less vigorous vegetative development resulted when the tricklers were at a distance of 50 cm. The salt concentration in the 0 to 30 cm soil layer increased with distance from the trickle line. Soil water tension was almost constant throughout the irrigation cycle at distances of 5-25 cm, it was lower at 0 cm from the tricklers, and markedly higher at 50 cm from the irrigation line. -- Copyright 1972, Biological Abstracts, Inc.

Hagood, M. A. (Washington State University, Prosser, Cooperative Extension 1972 Service). Automated irrigation is here. Agricultural Engineering, Vol. 53, No. 10, pp. 16-18, October 1972.

Displacement of rural Americans is an inevitable consequence of irrigation technology that will continue to displace inefficient equipment and labor. However, this new technology will add to the total growth, efficiency, and competitiveness of irrigated agriculture. Low-skilled labor is now being replaced with better trained, better paid, and more dependable managerial personnel. New irrigation systems make possible development of previously considered non-irrigable land. Trickle irrigation allows use of low quality water, as sprinkler irrigation allows water flow management which can significantly affect sediment concentration, nutrient content, and overall water quality of return flows. Automation of surface systems in open channels maintains uniform water levels, in addition to a 30% savings in water use. The costs of owning and operating selected sprinkler systems are presented and as the beneficial aspects of type and automation level of various systems are discussed.

Kligfield, George. (National Council for Research and Development, Jerusalem, 1967 Israel). Utilization of thermal water from nuclear power plants. Developments in Water Quality Research, Jerusalem International Conference on Water Quality and Pollution Research, Jerusalem, Israel, pp. 173-178, June 1967.

An approach to the utilization of warm waste waters from a paper and pulp plant for agricultural benefits and demonstration of the concept of thermal enrichment as opposed to thermal pollution

is presented in this paper. The procedure, which encompasses seven Oregon firms, began with the overhead sprinkling of warm water during three phases of the growing season, early spring to prevent freeze killing of fruitbuds, blossoms, and early fruit, normal ground crop irrigation, and fruit-burn prevention during hot dry periods. A three-year program for demonstration of the effects of heat energy contained in the irrigation waters to ascertain if warm water has a more beneficial effect on air temperature, humidity, and soil temperature than does the application of normal (cool) river or well water is given. Some conclusions are, (1) since this project aims at determining methods of introducing heat to soil, well and subsurface irrigation will be coupled with mulching techniques, (2) the tying together of nuclear power and agricultural promises major economic benefits, and (3) ponding, or a cooling lake, can be the key to the utilization of this water in the creation of new population centers and can provide as well, a tempered irrigation water supply.

Schmueli, M. and D. Goldberg. (Hebrew University, Jerusalem, Israel, Department of Irrigation). Emergence, early growth, and salinity of five vegetable crops germinated by sprinkle and trickle irrigation in an arid zone. Hortscience, 6(6 sec. 1), pp. 563-565, 1971.
1971

Field experiments were conducted to test the emergence, early growth, and salt build-up in soil and leaves with five vegetable crops germinated by sprinkle and trickle irrigation using saline water. In some of the crops (cucumber, tomatoe, pepper) trickle irrigation shortened the time until emergence and the stand was more uniform. Other crops (muskmelon, onion) responded in a similar manner to both irrigation methods. Seedling development was good with both methods. Trickling produced a higher salt concentration in the 0 to 3-cm soil layer of the crop row, although this had no apparent effect on emergence, seedling weight, or chloride content of the leaves.--Copyright 1972, Biological Abstracts, Inc.

Tscheschke, P., J. F. Alfaro, J. Keller, and R. J. Hanks. (Utah State University, Logan). Trickle irrigation soil water potential as influenced by management of highly saline water. Soil Science, Vol. 117, No. 4, pp. 226-231, 1974.
1974

The purpose was to determine the soil water potential and salt patterns in uniform soil profiles as a result of four different

water management treatments. Cherry tomatoe plants were irrigated, daily with a volume of water equal to that used by the plant on the previous day, every other day with volumes of water being equal, below the water evapotranspired, and above the water evapotranspired. Although trickle irrigation offers the possibility of good yields when nontoxic highly saline water is used to irrigate, accumulated salts in the root zone may be a potential hazard. Soil water potential decreased in the soil profile as a result of salt accumulation with increased distance from the trickle source. The highest salt concentration occurred in the profiles irrigated with volumes of water below that evapotranspired by the tomato plants. Indicating the importance of avoiding under irrigation when highly saline water is used with trickle irrigation. In addition, higher soil water potentials and higher yields resulted from irrigating

E. Crop Response

Abrol, I. P. and S. P. Dixit. (Punjab Agricultural University, Hissar, India, Department of Soils). Studies of the drip method of irrigation. Experimental Agriculture, Vol. 8, No. 2, pp. 171-175, 1972.
1972

Drip irrigation is the lateral spread of water at slightly above atmospheric pressure, in soil near the root zone of the growing crop, through a system of perforated plastic pipes buried in the soil. A comparison was made of drop and conventional check basin irrigation methods, using onion (Allium cepa) and ladies finger (Hibiscus esculentum) as test crops. In both cases, drip irrigated plants showed significant superiority in yield and water use efficiency. This was because of greater soil moisture availability at lower tensions and reduced surface evaporation losses. Bulb or root crops may be at any advantage because the wetter soil presents less resistance to expansion.

Allred, E. R. (Minnesota University, Minneapolis, Department of Agricultural Economics). Subsurface irrigation with heated water, its management and application toward reduction of thermal pollution problems. (Available from the National Technical Information Service, Springfield, Virgina 22161, as PB 236 036, $3 in paper copy, $2.95 in microfiche; Water Resources Research Center, University of Minnesota, St. Paul, mimeographed report) June 1974.
1974

The purpose was to evaluate the use of waste heat energy for the growing of agricultural crops in northern climates, to determine the basic heat transmissibility characteristics of soil, and to evaluate crop frost protection benefits as the result of the soil warming process. The layout and the procedures described are based on field studies on a hubbard loamy sand located at the sand plains experimental irrigation field, near Elk River, Minnesota. The following conclusions can be made for the data obtained, soil warming is necessary for extension of the growing season for field crops in Minnesota. Soil-warming cannot be done effectively by using an irrigation system alone. Artificial warming of a field soil by utilization of waste heat energy does not provide a significant protection for potatoes against frost at temperatures below 28°F. Maturity data for early potato varieties grown in heated soil can be advanced between two and three weeks, as compared to potatoes grown in unheated field soils. Only small quantities of waste heat energy can be utilized by a field soil in Minnesota during July and August. Moderate second crop yields are possible with heated soils in Minnesota, if replanting is done immediately following the first crop harvest. Because of unreasonably low air temperatures encountered in 1974, the early potato harvest data was not advanced appreciably over 1973, even though frost protection measures were installed.

Barlow, E. W. R., A. R. Sepaskhah, and L. Boersma. (Oregon State
1974 University, Corvallis, Department of Soil Science). Subsurface heating and irrigation of soils. Its effect on temperature and water content and on plant growth. (Available from the National Technical Information Service as PB 231 555, $4.50 in paper copy, $1.45 in microfiche, Oregon Water Resources Research Institute, Corvallis, Completion Report WRRI-23 March 1974.)

Subsurface irrigation even without heating the soil has given good results in terms of increased yields of crops and decreased water requirements in comparison with other methods of water application. Laboratory experiments were used to study the effect of heat source temperature on the temperature distribution around a line heat source in different soils. Different soil surface heat loads were applied to study the effect of varying climatic conditions on the temperature distributions. Effects of heat source temperature, soil surface temperature, and soil texture on rate of heat dissipation were studied. Water was applied near the heat source to determine the rate of water application required to maintain a constant soil water content at different heat source temperatures. Water content distributions

and rates of water application were measured. Concurrent experiments were conducted to determine the effect of lowering root temperature on plant growth by measuring the effects on plant water potential and its relation to leaf elongation, photosynthesis, and transpiration, using young corn plants.

Brosz, D. D. (South Dakota State University, Brookings, Water Resources
1974 Institute). Operation evaluation of irrigation systems. (Available from National Technical Information Service, Springfield, Virginia 22161 as PB 236-042, $3.25 in paper copy, $2.25 in microfiche, completion report, June 1974).

Three years' data were collected on yield responses of potato and corn crops irrigated by trickle, subsurface, and sprinkler irrigation systems. The field plots study included six irrigation system design treatments including every row and every other row trickle and subsurface irrigation, small frequent sprinkler application and larger infrequent sprinkler application. Potato and corn production can be increased by 5 to 10 percent with 20 percent less water when it is applied through the use of trickle and subsurface irrigation rather than through sprinklers. A water savings of approximately 30 to 40 percent can be achieved with trickle and subsurface irrigation for yields that are comparable to those obtained with sprinklers. Tensiometers installed in the plots did show that the soil water tension was higher for the trickle and subsurface plots. The irrigation system design treatments had no effect on potato crop maturity or quality. However, the corn grain quality for the sprinkler system applying small frequent irrigations was adversely affected because of black masses of spores (smut) appearing on the ears.

Bucks, D. A., L. J. Erie, and O. F. French. (Agricultural Research
1973 Service, Phoenix, Arizona, Water Conservation Laboratory). Trickle irrigation on cotton. Progressive Agriculture in Arizona, Vol. 25, No. 4, pp. 13-16, July-August 1973.

The objective of this field investigation on cotton has to evaluate the effects of limiting quantities and varying frequencies of trickle irrigation for maximum crop production. Cotton was chosen because it is a crop which is an excellent indicator of moisture stress. One year's data was gathered and analyzed from the University of Arizona's Cotton Research Center in Phoenix, on a relatively fine-textured clay loam soil with a previous field history of barley for one year and cotton for three years previous to barley. Total fertilizer

applied during the previous year and before planting was 420 lb/acre of urea, none thereafter. Criteria for trickle irrigation consisted of applying three quantities, based on ratios of the plant's consumptive--use estimate, at three frequencies. These nine treatment combinations were replicated four times in a split-plot design. Results suggest that the amount of soil moisture needed by the cotton plant for high production with trickle irrigation is approximately equal to the present consumptive--use estimate for furrow irrigation, and that increased frequency of trickle irrigation may not necessarily increase yields on fine-textured soil.

Ekern, P. C. (Hawaii University, Honolulu, Department of Agronomy and
1972 Soil Science). Drip irrigation in sugarcane. In Water Resources Seminar SEries, No. 1, January 1972, Water Resources Research Center, University of Hawaii, Honolulu, pp. 69-72.

Consumptive use of water by sprinkler and drip irrigated sugarcane was measured by four hydraulic load cell lysimeters at the Konia substation, Hawaii. The original one-eye cane transplants were set in Molokai Latosol in October 1968. Water use by the full canopy of sprinkler irrigated cane for both plant crop and ratoon approximated the evaporation from a ground level class A pan and often equalled or exceeded the full equivalent value of the local net radiation, indicative of positive heat advection. The fraction of sunlight converted into net radiation had a strong seasonal change from 0.53 in summer to 0.38 in winter over the cane. Drip replaced sprinkler irrigation in the fall of 1970. With full canopy, both the plant crop and ratoon cane used only 0.75 to 0.8 of the water from that used by sprinkler irrigated cane. Rainfall percolated through the 5 foot depth of soil in the lysimeters and removed approximately 400 lbs of nitrate/acre in the 15 inches of percolate during the winter of 1968-1969, and again in the 30 inches of percolate during the winter of 1970-1971. Yield and growth of cane was satisfactory for both the sprinkler and drip irrigation methods.

Goldberg, D. and M. Shmueli. (Hebrew University, Jerusalem, Israel).
1969 Trickle irrigation--a method for increased agricultural production under conditions of saline water and adverse soils. International Conference on Arid Lands in a Changing World, Arizona University, Tucson, June 3-13, 1969.

This paper reports on experiments employing drip irrigation in the Arava Desert region of Israel. The method is based on

the lateral spread of water by conduction under pressure and application through special nozzles placed on a plastic conveyor pipe just above the ground in close proximity to the plants. Experimental crops included muskmelons, tomatoes, cucumbers, sweet corn and peppers. Rate of growth under trickle irrigation surpassed that under sprinkler irrigation. This led to earlier, as well as higher, yields with reduced production costs, particularly water. Picking costs were reduced by uniform ripening and early market prices were higher. In many cases, under trickle irrigation, the salt concentration was the lowest possible under the specific prevailing conditions of saline water and saline soils of the area. Values for chloride content in plant leaves under trickle irrigation were between 40 to 60 percent of those for sprinkler irrigation. With very low rates of application the water supply very nearly equals the amount actually used by the plant.

Goldberg, D. and M. Shmueli. (Hebrew University, Jerusalem, Israel, Department of Irrigation). Sprinkle and trickle irrigation of green pepper in an arid zone. Hortscience 6(6 Sec. 1.), pp. 559-562, 1971.
1971

Pepper plants (Capsicum annuum L. cv. "California wonder") were sprinkle and trickle irrigated, each at two different frequences, during the growing season from September to April. Yield, leaf growth, and root development were all greater with trickle than with sprinkle irrigation. Frequency of water application had a slight, but non-significant effect. Yield tended to decrease when the plants were sprinkle irrigated daily. With trickle irrigation, the infrequent interval, every five days, tended to reduce the yield. Leaf chloride content was considerably greater under sprinkling, especially at the frequent interval.

Hiler, E. A. and T. A. Howell.(Texas A&M University, College Station). Crop response to trickle and subsurface irrigation. Paper 72-744, 1972 Annual Meeting American Society of Agricultural Engineers, Chicago, Illinois, December 1972.
1972

An investigation was conducted to compare water-use efficiencies using different irrigation methods, and to evaluate effects of reduced irrigation amounts on yields using trickle irrigation. Grain sorghum was grown during 1971-72 in a field lysimeter installation where complete control of the soil water could be maintained. Irrigation treatments included subsurface, trickle, subsurface plus mist, trickle plus mist, and surface. Water measurements were made to determine

irrigation amount, storage depletion, and drainage amount, so that total crop water use could be determined. Trickle and mist treatment resulted in the highest water efficiencies. The increase in water-use efficiency based on total water use was 42 percent for trickle treatment compared to surface treatment. Grain sorghum growth as indicated by crop height and leaf area index was greater for all 1971 intensive treatments than for the surface treatment. Comparison of three levels of trickle irrigation amounts in 1972 indicates that water-use efficiency increased by 50 percent with sparing trickle applications.

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Part II.

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