Annotated Bibliography on Trickle Irrigation

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FOREWARD

Trickle irrigation (or drip irrigation) is a relatively new approach to supplying agricultural crops with moisture where natural precipitation is inadequate. Research relating to trickle irrigation is being conducted throughout the world, including a significant effort in the United States. To date, the application of this irrigation method in Colorado has been considered feasible only in orchards or greenhouses. However, increased emphasis on improving irrigation water management capabilities for salinity control, revegetation of lands disturbed by mining activities, etc. necessitates further examination. This report presents a compilation of annotated references from approximately 30 sources of technical literature. Its purpose is to allow the reader to assess the existing knowledge and evaluate information relevant to the problems being encountered as well as indicating where further study is necessary.

Articles and reports described in this report were published between the late 1950's and early 1975. Discussions include design methods, hydraulics, crop response, salinity, water filtration, fertilization, irrigation scheduling, emitter design and clogging, wetting patterns, and other material pertinent to trickle irrigation. Each entry is listed alphabetically by senior author and key words describing the contents have been assigned with reference in the appendix.

Several articles in agricultural magazines which were general or descriptive in nature have been omitted. In addition, certain articles of a specialized nature relating to topics of limited interest were also excluded. Information describing water, salts, and nutrient flow systems pertinent to the conditions encountered under trickle irrigation is included.

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1. Aljibury, F.K., Gerdts, M., Lange, A., Huntamer, J., and Leavitt, G. *Performance of Plants with Drip Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 497-502. July 1974.

Experiments were established to study the effects of drip irrigation on water use efficiency and production in oranges along with the effects of drip and furrow irrigation on water penetration and performance of plums. Orange production records show that higher production with drip irrigation may be attributed to improved water penetration. Plum production records show no significant difference in production or fruit quality, but irrigation efficiency was improved.

2. Aljibury, F.K., Marsh, A.W., and Huntamer, J. *Water Use With Drip Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 341-345. July 1974.

In the absence of proper equations to calculate water requirements with drip irrigation, irrigation consultants and dealers in California have used the same water use data developed for conventional irrigation systems. Since one of the primary advantages of drip irrigation is water savings, development of water budget to fit drip irrigation became necessary. To accomplish this objective, several drip irrigation studies were initiated in the San Joaquin Valley of California. These studies were conducted on farms where citrus, avocados, plums, olives, and grapes were grown. Applied water was measured using flow meters while the frequency and amount of water application was determined with tensiometers set to switch the water on at 30 centibars. Water evaporation from Class A pans established in large alfalfa fields was recorder regularly. A table is presented showing suggested drip water application as a function of Clas A pan evaporation and percent plant coverage.

3. Anonymous. *Drip Irrigation Scheduling Using Class A Evaporation Pans.* Controlled Water Emission Systems, El Cajon, California.

This report shows how daily readings from a Class A Pan can be used to determine the drip irrigation schedule for a particular set of growing conditions. It is best used on established trees, vines, and plants. New plantings should be irrigated strictly by tensiometers placed carefully within the root zone.

4. Bernstein, L. and Francois, L.E. *Comparisons of Drip, Furrow, and Sprinkler Irrigation.* Soil Science, Vol. 115, No. 1, pp. 73-86. 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 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 95 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.

5. Bester, D.H., Lotter, D.C., and Veldman, G.H. *Drip Irrigation on Citrus*. Proceedings of the Second International Drip Irrigation Congress, pp. 58-64. July 1974.

A study was conducted on citrus to establish the comparative efficiency of drip irrigation, dragline sprinkler irrigation, and a hose system discharging water directly into irrigation basins in South Africa. The following aspects of drip irrigation were investigated:

1) Soil moisture determinations and wetting patterns
2) The possibility of using an evaporation pan to determine irrigation requirements
3) The effect of different numbers and spacing of drippers per tree
4) The effect of different dripper discharge rates
5) Practicability of using microtubes as drippers
6) The possibility of applying fertilizers through a drip irrigation network
7) Factors affecting the distribution efficiency of a drip irrigation system.

6. Bhuiyan, S.I., Hiler, E.A. and van Bavel, C.H.M. *Dynamic Modeling for Subirrigation System Design*. American Society of Agricultural Engineers, Paper No. 71-716. 1971.

A computer model in S/360 CSMP was developed to describe transient vertical flow of water from a buried source and its redistribution in unsaturated soil. The model takes into account the effect of gravity and of water uptake by plant roots as a dynamic process. Simulated data were obtained for three different levels of the source and their comparative conditions were discussed. Two new concepts which evaluate the vertical water-distribution efficiency in a subirrigation system are introduced. Subirrigation design criteria are defined. An approach to determine the optimum depth of the source is presented.

7. Black, J.D.F., and Mitchell, P.O. *Change in Root Distribution of Mature Pear Trees in Response to Trickle Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 437-438. July 1974.

Work was undertaken to obtain an idea of the rate of adaption of the root distribution of pear trees grown under uniform sprinkler irrigation for 18 years and then converted to trickle irrigation for two years with one emitter per tree. Flow rate per emitter was 8 ℓ per hour per tree. After two seasons the entire root system of 4 trees was exposed and examined for changes in response to the continuously moist but restricted wetted soil volume in the root zone. The intensity of new root growth was markedly higher inside the wetted soil volume.

8. Black, J.D.F., and West, D.W. *Water Uptake by an Apple Tree with Various Proportions of the Root System Supplied with Water.* Proceedings of the Second International Drip Irrigation Congress, pp. 432-433. July 1974.

Water uptake by young apple trees with 1/4, 1/2, and 3/4 of their root systems supplied with water was related to the uptake with the total system supplied with water in a split root pot trial. The respective percentages of water uptake compared with the totally watered system were 74, 88, and 94 percent.

9. Blass, S. *Drip Irrigation.* 26 Mane Street, Tel-Aviv, Israel. July 1969.

This publication discusses the history of drip irrigation in Israel and presents information on specific products, design, application rates, and results, etc. of work conducted or in progress in Israel. The extensive use of the drip irrigation method started in Israel in 1966. The drip irrigation method allows for larger yields, better quality crops, labor savings, and water savings.

10. Brandt, A., Bresler, E., Diner, N., Ben-Asher, I. Heller, J., and Goldberg, D. *Infiltration from a Trickle Source: I. Mathematical Models.* Soil Science Society of America Proceedings, Vol. 35, ppl 675-682. 1971.

Theoretical considerations were used to develop mathematical tools to analyze two 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 add difference 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 field water content, the saturated water entry zone, and the water flux at the soil surface.

11. Branson, R.L., Gustafson, C.D., Marsh, A.W., Davis, S., and Strohman, R.A. *Monitoring Soil Salinity and Leaf Nutrient Levels in a Young Avocado Orchard Under Drip Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 364-367. July 1974.

Salinity control is an important part of the management program for avocado production because of the crop's low tolerance to salts. Soil salinity in the root zone of a newly planted avocado orchard was monitored for four years. The orchard, located in a semi-arid region of southern California, is irrigated with a moderately saline water from the Colorado River. Soil salinity rose to marginal levels during each irrigation season under both irrigation methods. Winter rainfall, however, leached accumulated salts from the soil each year. Distribution of the rainfall, as well as total amount, was an important factor with regard to adequacy of leaching. Leaf samples were analyzed annually to obtain information on the uptake of chloride, an ion toxic to avocado at relatively low levels. Leaf analysis data are also being used to evaluate the fertilization program.

12. Braud, H.J. *Discharge of Water Through Slits in Polyethylene Plastic Pipe.* Bulletin No. 615, Agricultural Experiment Station, Louisiana State University, Baton Rouge. 1967.

The low cost and long service life of flexible polyethylene plastic pipe makes it readily adaptable to underground irrigation systems. Preliminary calculations of the flow requirements for perforated lines indicated that small-diameter pipe can be used for underground water distribution, and that the pressure required to inject water into the soil mass is of such small magnitude that commercial pipe with perforations cut into it can be used without structural failure. The size and shape of openings which can be used for releasing water is exrememly variable. In order to ascertain the discharge characteristics of longitudinal slits in polyethylene pipe, laboratory calibrations were run using a wide range of slit lengths and pipe sizes. Prediction equations were developed to relate flow rate to pressure, pipe dimensions, and slit length for two types of commercial polyethylene plastic pipe.

13. Bresler, E., Heller, J., Diner, N., Ben-Asher, I., and Goldberg, D. *Infiltration from a Trickle Source: II. Experimental Data and Theoretical Predictions.* Soil Science Society of America Proceedings, Vol. 35, pp. 683-689. 1971.

The theory of transient infiltration from a trickle source was compared with experimental results. Field data were collected from a sandy soil that was wetted by commercial tricklers. The agreement between theory and experiment, as expressed by water content distribution and location of the wetting front, is generally good and suggests that the theory is applicable to many field situations. The theory and experimental data indicate that for the conditions studied, an increase in the trickle discharge rate results in an increase in the horizontal wetted area and a decrease in the soil wetted depth. Hysteresis becomes 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.

14. Bresler, E., Kemper, W.D:, and Hanks, R.J. *Infiltration, Redistribution, and Subsequent Evaporation of Water from Soil as Affected by Wetting Rate and Hysteresis.* Proceedings of the Soil Science Society of America, Vol. 33, pp. 832-840. 1969.

Soil columns were wetted at three different rates causing unequal water content profiles during infiltration. Water content profiles during infiltration, redistribution, and evaporation were observed experimentally and computed using a numerical solution of the isothermal flow equation. Each wetting rate resulted in a different drying water retention curve. The hysteresis in soil water content-water section relationships had a larger influence as the wetting rate increased. Hysteresis effects tend to keep the water content higher and the zone of wetting shallower during the redistribution stage when rates of wetting are faster. Higher water content and lower wetting depth at any redistribution time caused subsequent evaporation to be greater. Evaporation was directly related to the previous wetting rate, either when the soil was subjected to evaporation immediately following infiltration or when subjected to evaporation after redistribution for 4 days. The differences in evaporation between the three wetting treatments were significant at the 99 percent probability level. Allowing time for redistribution decreased evaporation compared to evaporation and redistirbution occurring simultaneously. The effects of wetting rates and hysteresis on water content profiles and evaporation were similar in the experimental and computed results.

15. Brosz, D.D. *Trickle Irrigation.* South Dakota Agricultural Experiment Station, South Dakota Farm and Home Research, Vol. 25, No. 2. 1974.

Trickle irrigation has been tested on potatoes and corn while vegetables and strawberries will be trickle irrigated and studied by S.D.S.U. agricultural engineers. Results show that higher yields can normally be expected from plots irrigated by trickle and subsurface systems with 20-40 percent water savings.

16. Bucks, D.A., Erie, L.J., and French, O.F. *Trickle Irrigation on Cotton.* Progressive Agriculture in Arizona, Vol. XXV, No. 4, pp. 13-16. 1973.

Quantity and frequency of trickle irrigation were varied to develop management criteria for maximum cotton production and increased water-use efficiency. Trickle irrigations consisted of 1.06, 0.90, and 0.72 times the present consumptive-use estimate for furrow irrigation applied at three frequencies of three, six and twelve days. Frequencies of trickle irrigation showed no significant effect on lint production between three, six and twelve days for all irrigation quantities. Results suggest 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 a fine-textured soil.

17. Bucks, D.A., Erie, L.J., and French, O.F. *Quantity and Frequency of Trickle and Furrow Irrigation for Efficient Cabbage Production.* Agronomy Journal, Vol. 66, No. 1, pp. 53-57. 1974.

Trickle irrigation, with its capability of small, frequent irrigation applications, has aroused considerable interest because of possible increased production and decreased water requirements. For this reason, a replicated field investigation was conducted to evaluate quantity and frequency of trickle, modified-furrow, and standard-furrow irrigations on the growth of cabbage, using a moderately saline water on a fine-textured soil. Trickle and modified-furrow irrigation were scheduled to supply various quantities of water based on ratios of the plant's estimated consumptive use at frequencies of 3, 6, and 12 days. Recorded data included yield, quality of production, and water-use efficiency. Results indicate that the consumptive-use requirement (38 cm of water in 1972) for high production of cabbage was about the same for all irrigation methods. Trickle and modified-furrow irrigation, however, did reduce the irrigation water requirement as compared with the standard-furrow irrigation, showing that higher irrigation efficiencies can be attained with these new irrigation methods.

18. Bucks, D.A., Erie, L.J., and French, O.F. *Trickle Irrigation Management for Cotton and Cabbage.* Proceedings of the Second International Drip Irrigation Congress, pp. 351-356. July 1974.

Cotton and cabbage studies were initiated to evaluate the effects on crop production of specified quantities and frequencies of water applications using trickle irrigation. Different quantities of irrigation water were applied at frequencies of 3, 6, and 12 days. Both studies were conducted on small plots of fine-textured, clay-loam soil, using a moderately saline water. Results of these studies indicate the following: (1) the amount of soil moisture needed by the cotton and cabbage plants for high production was approximately the same as the presently-accepted consumptive use; (2) increasing frequency of trickle to 3 days did not increase yields on this soil; and (3) trickle irrigation can decrease irrigation water requirements under conditions where furrow irrigation would not attain a high overall irrigation efficiency.

19. Bucks, D.A., Erie, L.J., Nakavama, F.S., and French, O.F. *Trickle Irrigation Management for Grapes*. Proceedings of the Second International Drip Irrigation Congress, pp. 503-507. July 1974.

A three-year field invesitgation is being conducted to determine irrigation management and design requirements for grape production. Trickle irrigation treatments include three irrigation quantities, based on ratios of a consumptive-use estimate; three irrigation frequencies--daily, 3-day and 6-day; and a variation of one or two trickle irrigation emitters per vine. Furrow irrigation treatments include the same three seasonal quantities used for the trickle irrigation applied in two or three furrows per vine; however, the irrigation frequency is varied, based on the consumptive use. First-year results were as follows: there was a 13 percent increase in yield for trickle irrigation with two emitters per vine over one emitter per vine; a 6 percent increase in berry size for trickle-irrigated fruit over furrow-irrigated; little difference in sugar content between irrigation treatments; and little difference in yield between trickle irrigation frequencies.

20. Bucks, D.A. and Myers, L.E. *Trickle Irrigation--Application Uniformity from Simple Emitters*. Transactions of the American Society of Agricultural Engineers, Vol. 16, No. 6, pp. 1108-1111. 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.

21. Busch, C.D., and Kneebone, W.R. *Subsurface Irrigation with Perforated Plastic Pipe.* Transactions of the American Society of Agricultural Engineers, Vol. 9, No. 1, pp. 100-101. 1966.

Turf data have shown that sprinkler and subsurface irrigation can be managed for comparable water use and turf quality on an established crop. However, model studies emphasize that the distribution pattern inherent in a buried perforated-pipe system can give rise to problems of uniformity and excess water application under certain conditions.

22. Cataluna, D.C. *Drip Irrigation of Macadamia Nut Trees at Hawaiian Orchards Company, Pahala, Hawaii.* Proceedings of the Subsurface and Drip Irrigation Seminar, University of Hawaii, Misc. Pub. No. 102, pp. 30-33. 1973.

Although drip irrigation is not a dramatic system, it is dynamic--the newest "in" thing in agriculture. Drip irrigation uses small quantities of water at low pressures and increases yields and revenues.

23. Cole, P.J., and Till, M.R. *Response of Mature Citrus Trees on Deep Sandy Soil to Drip Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 521-526. July 1974.

A demonstration trial on mature vallencia oranges was established to provide guidelines for future drip irrigation management in Australia. The trees are on a deep sandy soil and were established and previously maintained by sprinkler irrigation. There may be up to 456 mg/l total dissolved salts in the irrigation water. Two designs of drip irrigation have been used--one with a row of drippers along the base of the trees only, and the other with a line along both the base and in midrow. There are twice the number of drippers in this latter system, each of half the flow rate of the former. A difference in performance of trees irrigated by the two designs, and also with sprinkler irrigated trees, has been observed. Drip irrigated trees are yielding less than sprinkler irrigated trees, however, the double line drip irrigation yields better than single line drip irrigation.

24. Coppock, R.H., and Osterli, V.P. *Drip Irrigation: What Does It Promise for Water Conservation?* Cooperative Extension, University of California, Number 15. Sept/Oct 1973.

Drip irrigation is a method of applying water to growing plants almost continuously, a few drops at a time. It makes use of small plastic pipes along the surface of the soil and plastic "emitters" that release from half a gallon to two gallons of water per hour.

25. Dan, C. *Influence of Different Amounts of Irrigation--Water, Irrigation--Intervals and Fertilizer on the Yield and Quantity of Drip-Irrigated Musk-and Watermelons.* Proceedings of the Second International Drip Irrigation Congress, pp. 425-430. July 1974.

Trials were initiated to determine irrigation and fertilization practices to promote high muskmelon and watermelon yields of satsifactory quality. Yields were not affected by different amounts of irrigation water or by different irrigation schedules.

26. Dan, C. *The Irrigation of Olives by Drip and Other Irrigation Methods.* Proceedings of the Second International Drip Irrigation Congress, pp. 491-496. July 1974.

Drip irrigated young trees gave higher and earlier yields before attaining full maturity than trees irrigated by any other method. The number of emitters per tree was not found to be critical in the range of 4 to 8 emitters per tree. The yields of mature trees which were converted to trickle irrigation were generally somewhat higher than before.

27. Davis, S., and Nelson, S.D. *Subsurface Irrigation Easily Automated.* Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 96, No. IR1. March 1970.

Subsurface irrigation systems are being used successfully to irrigate potatoes, citrus, and ornamental plantings in California. The application of water can be regulated by any suitable automatic, mechanical, or manual control. Installation and removal of a subsurface irrigation system for row crops has been automated. The effectiveness of a subsurface irrigation system for potato production has been demonstrated in field-sized plots.

28. Davis, S., and Pugh, W.J. *Drip Irrigation: Surface and Subsurface Compared with Sprinkler and Furrow.* Proceedings of the Second International Drip Irrigation Congress, pp. 109-114. July 1974.

This paper reports on four studies that compared crop response to various combinations of drip, subsurface, furrow and sprinkler irrigation. Study concludes that: (1) when the amount of water applied is near the consumptive use requirement, subsurface irrigation has greater production and better water use efficiency; (2) less water is needed for drip and subsurface irrigation than for furrow or sprinkler irrigation, because less water is lost to direct evaporation and deep percolation; and (3) the applicators used applied water equally well to the surface or subsurface soil, except where deposits from evaporation occurred.

29. Davis, S., and Pugh, W.J. *Dripper Flow Consistency*. Proceedings of the Second International Drip Irrigation Congress, pp. 281-283. July 1974.

Several different emitters have been checked for flow consistency volumetrically, both in time for the same emitter and for several emitters along the applicator line. Results of two years' study show many of the applicators vary more than ±5 percent from the average. With the exception of a few drippers that were partially clogged or improperly manufactured, most of the drippers provided consistent water distribuiton both along the line and with time.

30. Davis, K.R., and Spencer, W.F. *Soil Salinity Distribution in Drip and Subsurface Irrigated Summer Squash*. Proceedings of the Second International Drip Irrigation Congress, pp. 358-363. July 1974.

Salt and water distribution patterns were determined around a porous tubing as part of a study to evaluate several drip and subsurface irrigation lines at Riverside, California. Generalized plot sampling after seasonal rainfall established initial soil salinity and water levels. A detailed scheme was employed for mid-season and end-season soil sampling. Soil salinity and water distributions before, during, and after the 1973 growing season of zucchini squash are discussed.

31. DeRemer, E.D. *A Simple Method of Drip Irrigation*. Irrigation Journal, Vol. 22, No. 3, pp. 10-15. 1972.

The drip method of irrigation is discussed and a method of computing the timing and amount of the irrigation is presented.

32. Deshmukh, M.T. *Development and Scope of Drip and Subsurface Irrigation*. Proceedings of the Second International Drip Irrigation Congress, pp. 52-57. July 1974.

Drip irrigation is quite suitable for arid and semi-arid regions characterized by poor saline soil, saline irrigation water and high evapotranspiration rates. In this method, water is applied slowly and continuously to the crops on the ground surface with the help of pipes having perforations or emitters fixed at suitable intervals along the length of the pipe. This paper reviews the developments in the drip method of irrigation.

33. Deshmukh, M.T., and Jain, M.L. *Evaluation of Hydraulics of Flow Through Pipes of Varying Slopes, Lengths and Orifice Placements*. Proceedings of the Second International Drip Irrigation Congress, pp. 317-321. July 1974.

Polyethylene pipes with 1/2" diameter and 1/16" size perforations have been used to study the hydraulics of flow, under laboratory conditions. The variables considered for study were (i) length of the pipe, (ii) spacing of perforations (iii) pipe slope (iv) placement of perforations (facing upward, downward and sidewise) and (v) operating pressure (up to 5 ft.). Three repeated readings have been taken for each test and validity of the results showing relationship of discharge with variables considered has been established with suitable tests.

34. Doss, B.D., and Pearson, R.W. *Response of Soybeans to Subirrigation.* Soil Science, Vol. 114, No. 4, pp. 264-262. 1972.

Study purpose was to determine the maximum yields obtained when soybeans were furnished a continuous supply of water by subirrigation and to compare yields and water use efficiency with subirrigated and surface irrigated treatments. Soybeans responded to irrigation in both plant height and bean yield, but subsurface application did not prove to have any advantages over surface application. Although plants were not allowed to experience moisture stress at any time during the growth cycle in the subirrigated treatment, yields were not significantly higher than for the surface irrigated treatment, and efficiency of water use was much lower.

35. Ekern, P.C. *Drip Irrigation of Sugarcane.* Water Resources Seminar Series No. 4, Water Resources Research Center, University of Hawaii, Honolulu. June 1974.

More efficient use of irrigation water for sugarcane production can result from more uniform distribution of the water, management to reduce deep percolation, reduce loss by direct soil evaporation rather than plant transpiration or by greater growth if intermittent water stress can be minimized. Frequent drip applications keep water stress minimal and plant growth is encouraged if nutrients are available.

36. European Commission on Agriculture. *Trickle Irrigation.* Working Party on Water Resources and Irrigation, Food and Agricultural Organization of the United Nations, Rome. 1973.

This review of experience gained with trickle irrigation has been undertaken in consideration of the fact that there are countries where trickle irrigation has now developed beyond the stage of an experimental system, and that both developed and underdeveloped countries are very eager to learn from their experience. Work by researchers in France, Italy, Israel, and the United Kingdom is reported.

37. Farrell, M.D. *The Use of Self-Propelled Sprinkler Systems and Drip Irrigation in Sugarcane.* Annual Technical Conference, Sprinkler Irrigation Association, pp. 47-53. 1973.

The use of self-propelled center pivot sprinklers, hose-pull sprinklers, and drip irrigation is discussed. All three irrigation systems have proven to be reliable and efficient means of irrigating sugarcane. Flat culture made possible because of no requirement for deep furrows offers many advantages to sugarcane farming. The advantages of flat culture practice such as mechanical cultivation (including weed control, fertilization, and replanting) and the elimination of the infield handwork associated with surface irrigation systems are realized when these systems are used.

38. Farrell, M.D. *Drip Irrigation in Landscaping and Soil Erosion Control.* Proceedings of the Second Interntaional Drip Irrigation Congress, pp. 44-45. July 1974.

Article briefly discusses design, filtration, problems, and controls with drip irrigation in landscaping situations.

39. Fok, Y.S. *A Study of Two-Dimensional Infiltration.* Transactions of the American Society of Agricultural Engineers, Vol. 13, No. 5, pp. 676-681. 1970.

Laboratory studies have been made to correlate the observed two-dimensional infiltration with the observed horizontal and vertical soil moisture movements. The exponents of the infiltration equation may be expressed as the sum of the exponents of the horizontal and vertical soil moisture movement equations. The significance of the infiltration equation may be expressed as the sum of the exponents of the horizontal and vertical soil moisture movement equations. The significance of the infiltration geometry has also been studied. The exponent of the infiltration equation varies with the width and depth of the ditch and the ultimate value of the exponent equals the exponent of the vertical downward soil moisture movement equation.

40. Fok, Y., and Willardson, L.S. *Subsurface Irrigation System Analysis and Design.* Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers. September 1971.

A method for analysis and design of a subsurface irrigation system is presented. By using experimentally observed soil-water movement data, the required flow capacity of the system can be evaluated, the burial depth and spacing of the subsurface irrigation pipe may be designed, and the irrigation time may be obtained. The spacing of the subsurface irrigation pipe may be a limiting economic factor if close spacings are required.

41. Ford, H.W., and Tucker, D.P.H. *Clogging of Drip Systems from Metabolic Products of Iron and Sulfur Bacteria.* Proceedings of the Second International Drip Irrigation Congress, pp. 212-214. July 1974.

Numerous drip irrigation systems have been installed in central and south Florida citrus groves. Many have ceased to function properly because of filter and emitter clotting. The most serious clogging, involving water from shallow and deep wells, has been found associated with a sulfur bacteria. The long filamentous bacteria, stuffed with sulfur from the oxidation of hydrogen sulfide within the irrigation pipes, clog all small openings within a brief period of time. The white, slimy organic-sulfur-ion mass can only be dissolved in pyridine. Another serious clogging factor, from wells containing traces of ferrous iron, has been a filamentous gelatinous iron deposit (ochre) caused by iron bacteria. The sticky sludge adheres to filters and the grooves and orifices of emitters.

42. Fox, R.L., Phelan, J.T., and Criddle, W.D. *Design of Subirrigation Systems.* Agricultural Engineering, Vol. 37, No. 2. February 1956.

Subirrigation might be defined as a method of irrigating where the water supply for the crop comes from underneath the surface of the land. It depends on creating an artificial water table and maintaining it at some predetermined depth below the ground surface. Moisture then reaches the plant roots through capillary movement upward. Feeder ditches are designed and spaced such that the water table under the land can be raised and maintained at the proper elevation for optimum crop growth without too much variation in the depth from the land surface to the water table.

43. Fraser, G.O. *Drip Irrigations Inherent Requisite--Water Quality.* Proceedings of the Second International Drip Irrigation Congress, pp. 81-85. July 1974.

Article discussed reasons why water quality is of the utmost importance and what factors cause deterioration of water quality. Methods of filtering irrigation water are presented.

44. Freeburg, R.S., Cotter, D.J., and Urquhart, N.S. *An Explanation for the Growth Advantage of Drip Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 265-270. July 1974.

Soil, leaf, and air temperatures were measured for sweet corn during a 16-day period following emergence. The corn was grown in an experiment designed to compare trickle (drip) irrigation to furrow irrigation. There were significant differences between the temperature regimes produced by the two irrigation methods. The effects were especially notable in the soil temperatures. Based on a soil temperature of $80^{o}F$, which research literature indicates to be optimum for corn growth, an integrated deviation from optimum was computed for each irrigation method. Deviations above the optimum at the two-inch depth were only 785 degree-hours for the trickle system as compared to 1238 degree-hours for the furrow system during the 16-day period. During this period, the growth rate of the crop under furrow irrigation was 84 percent of that under the trickle irrigation.

45. Frith, G.J.T., and Nichols, D.G. *Effects of Nitrogen Fertilizer Applications to Part of a Root System.* Proceedings of the Second International Drip Irrigation Congress, pp. 434-436. July 1974.

It is usual under trickle irrigation of mature fruit trees to have considerable less than the total root volume wetted. If satisfactory nutrition of these trees is to be achieved with fertilizer dissolved in the irrigation water, then the wetter roots must increase their efficiency of nutrient uptake in a manner similar to their increased water uptake. Trials with split root seedling apple trees grown in water culture has shown that the nitrogen uptake efficiency of roots is increased as the proportion of the root system supplied with nitrate nitrogen is decreased. The efficiency of water uptake from those parts of the root system supplied with nitrate nitrogen was also increased over the level of uptake in quarters without nutrients.

46. Furuta, T., Besemer, S., Jones, W.W., Strohman, R., and Mock, T. *Irrigation for Benches.* Proceedings of Second International Drip Irrigation Congress, pp. 149-154. July 1974.

A series of experiments were conducted on the modification of existing irrigation systems and the use of drip irrigation for crops grown in benches. Where the system was properly designed, excellent plant growth and yield resulted from the use of modified nozzle irrigation systems, and from the use of drip systems, both individual emitters and tubes with small orifices. As measured by plant performance, water was more uniformly distributed in the soil where drip or the modified nozzle system was used, compared to established irrigation systems. Even with soils amended with large volumes of organic matter, uniform distribution of water occurred, although the surface between emitters was dry. Also excellent crops were produced in a soil that would be considered too tight or heavy for use in a bench. Considerable savings in the amount of water used and a corresponding reduction of the volume of run-off resulted.

47. Furuta, T., Branson, R., Jones, W.C., Strohman, R., Mock, T., and Ramadan, I. *Irrigation for Container Growing*. Proceedings of the Second International Drip Irrigation Congress, pp. 155-158. July 1974.

Trickle irrigation and modifications have been used for container growing, especially under greenhouse conditions, for more than a decade. Microtubing has been generally used. Difficulties with uniform wetting of the entire soil mass had been encountered. This and other problems have limited the use of trickle irrigation. With the development of emitters for containers, it became possible to study the use of drip irrigation for container growing. A series of experiments was conducted to study the soil mixture-fertilization-irrigation subsystem, varying each factor simultaneously. Larger plants--tops and roots--were noted under drip irrigation. These plants had higher N content initially and lower Na and Cl content late in the experiment. Root distribution within the container was also influenced with more roots in the center of the ball. Considerably less water was used with drip irrigation than with overhead sprinkling. The method of irrigation influenced salinity, nutrient content of drainage water and the wetting pattern in the soil.

48. Geraldson, C.M. *A Constant Micro Source of Moisture as a Component in a Gradient System for a High Level Production*. Proceedings of the Second International Drip Irrigation Congress, pp. 131-136. July 1974.

The objective of this study was to evaluate the use of a constant micro source of moisture which could be used as an alternative to a constant water table in establishing nutrient gradients for optimal production. Constant moisture was supplied by drip (trickle system) or by micro pore tubing. Soluble nutrients were supplied primarily by banded placement on the soil bed surface. Relative placement of fertilizer, moisture and plants as the major variables were evaluated in conjunction with different soils as well as the sources of moisture. A consistent high level production of vegetables and flowers was attained by integrating contributing components such as soil, moisture, fertilizer and plants to establish the desired gradient system. The resultant effect in conjunction with synthetic mulch as a protective component minimizes or eliminates these components as contributing variables.

49. Gerard, C.J. *Drip and Furrow Irrigation Studies on Sugarcane*. Proceedings of the Second International Drip Irrigation Congress, pp. 329-331. July 1974.

Research was conducted to evaluate the influences of drip and furrow irrigation on growth and yield of sugarcane in 1972 and 1973 in the Lower Rio Grande Valley of Texas. Drip irrigation treatments were 0, 25, 50, 75, and 100 and 0, 50, 75, 100 and 125 percent pan evaporation in 1972 and 1973, respectively. Yield of sugarcane was a linear function of applied water in 1972 with yields ranging from 35 to 51 tons per acre. Drip irrigation treatments are greater than or equal to 0.5 pan evaporation maintained rapid stalk elongation in early May and June in 1972. Rapid stalk elongation in July, August and September was maintained when the water applied was greater than or equal to 0.75 pan evaporation. Soil moisture, salinity conditions and root growth as influence by treatments, emitter sites and soil depth were evaluated. These findings and their implications are discussed.

50. Gibson, W. *Subsurface and Drip Irrigation for Hawaiian Sugarcane.* Proceedings of the Subsurface and Drip Irrigation Seminar, University of Hawaii, Miscellaneous Publication No. 102, pp. 3-4. January 1973.

Subsurface or drip irrigation systems appear to overcome the inherent disadvantages of furrow irrigation and sprinkler systems because they continuously "feed" the sugarcane roots through a network of small tubes installed along the cane lines. The advantages may be summarized as follows: relatively low capital cost, increased water efficiency, high irrigation performance, elimination of furrows with the associated costs, continuous "feeding," increased fertilizer efficiency, and decreased weed control costs.

51. Gilaad, Y., Krystal, L., and Zanker, K. *Hydraulic and Mechanical Properties of Drippers.* Proceedings of the Second International Drip Irrigation Congress, pp. 311-316. July 1974.

Article discussed research dealing with the hydraulic, mechanical, and functional requirements of the various types of emitters available based on hydraulic tests performed and experience accumulated in the field. The following hydraulic properties have a direct influence on the operation of drippers: the relationship between flow rate and pressure, resistance to the flow of water in the tubing at the place of insertion of the dripper, and shape and size of the water passage in the dripper.

52. Gilley, J.R., and Allred, E.R. *Optimum Lateral Placement for Subsurface Irrigation Systems.* Proceedings of the Second International Drip Irrigation Congress, pp. 234-239. July 1974.

Design of a subsurface irrigation system requires both the proper placement of the lateral line in the soil profile and proper lateral discharge. The lateral placement depends on the nature of the soil-moisture movement from the applicator and the extraction pattern of the irrigated crop. The optimum location of the laterals will therefore vary with soil type and the crop being irrigated. A mathematical model describing soil-moisture movement during subsurface irrigation has been developed. The results of the portion of the model describing infiltration from the subsurface lateral compare quite favorably with data available in the literature. A series of one dimensional sinks, to simulate soil-moisture extraction by plants, has been combined with the infiltration model to obtain a model of soil-moisture movement during subsurface irrigation. The model was used to determine optimum lateral placement as a function of soil type and crop root zone depth to obtain the desired crop extraction patterns. Results of the model indicate the optimum lateral placements also have higher irrigation efficiencies than other placement values. These variables were used to develop design curves relating lateral depth, spacing and discharge to soil type and crop extraction pattern. Results also indicate that for proper design, lateral depth is more important than lateral spacing.

53. Gitlin, H.M. *Soil Water Movement Under Drip Irrigation.* Proceedings of the Subsurface and Drip Irrigation Seminar, University of Hawaii, Misc. Publication No. 102, pp. 22-24. January 1973.

A drip irrigaiton system may be divided into two distinct regimes--the internal and the external. The internal regime is the total system of confined water; the external regime is the soil-air environment that the emitted drop enters. The purpose of the first is to create a desired effect in the second regime.

54. Goldberg, D., Gornat, B., Schmueli, M., Ben-Asher, I, and Rinot, M. *Increasing the Agricultural Use of Saline Water by Means of Trickle Irrigation.* Water Resources Bulletin, Vol. 7, pp. 802-807. 1971.

A study was conducted in two arid zones to determine the effect of saline water applied to various crops growing in a coarse-textured soil, using trickle irrigation. The test crops responded most favorably to this new method of water application in terms of plant development and yield. The method provides the possiblity of raising the permissible salinity level of irrigation water, thus increasing the water reserves suitable for agricultural use in the world.

55. Goldberg, D., Rinot, M., and Karu, N. *Effect of Trickle Irrigation Intervals on Distribution and Utilization of Soil Moisture in a Vineyard.* Soil Science Society of America Proceedings, Vol. 35, pp. 127-130. 1971.

In an established vineyard on sandy clay soil the effect of trickle irrigation interval on soil moisture and salt distribution and relative water used 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 positively affected by shorter irrigation intervals both in terms of grape production and of weight of prunings.

56. Goldberg, D., and Shmueli, M. *Drip Irrigation--A Method Used Under Arid and Desert Conditions of High Water and Soil Salinity.* Transactions of the American Society of Agricultural Engineers, Vol. 13, No. 1, pp. 38-41. 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 results is presented which support these conclusions. Also a technical description of the system is included and certain soil problems as they relate to the drip irrigation method are discussed.

57. Goldberg, D., and Shmueli, M. *Sprinkle and Trickle Irrigation of Green Pepper in an Arid Zone.* HortScience, Vol. 6, pp. 559-562. 1971.

Pepper plants were sprinkle and trickle irrigated, each at 2 different frequencies, 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 nonsignificant effect. Yield tended to decrease when the plants were sprinkle irrigated daily. With trickle irrigation, the infrequent interval, every 5 days, tended to reduce the yield. Leaf chloride content was considerably greater under sprinkling, especially at the frequent interval.

58. Goldberg, D., and Shmueli, M. *The Effect of Distance from the Tricklers on Soil Salinity and Growth and Yield of Sweet Corn in an Arid Zone.* Hortscience, Vol. 6. December 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. Nozzles located 5 to 25 cm from the plants produced the greatest yields. The salt concentration in the 0 to 30 cm soil layer increased with distance from the trickle line. Soil water tension was essentially constant throughout the irrigation cycle between 5 and 30 cm distance, but it was lower at 0 cm from the tricklers, and markedly higher at 50 cm from the tricklers.

59. Goldberg, S.D., and Uzrad, M. *Strip Cultivation of the Area Wetted by Drip Irrigation in the Arava Desert.* Proceedings of the Second International Drip Irrigation Congress, pp. 142-147. July 1974.

Drip Irrigation cultivation is in effect strip cultivation and in fact it represents almost the most intensive form of cultivation. Throughout the growing season the cultivated strip gets a most intensive set of treatments. Under arid climatic conditions in light soils and with saline water (like in the Arava), it is safe to assume that these strips will undergo considerable chemical and physical changes which would materially differ from the intermediary uncultivated strips. The problem posed was whether the cultivated strips were better, worse, or of no difference compared to the uncultivated strips. Results show that the cultivated strips were superior to the uncultivated strips.

60. Grobbelaar, H.L., and Lourens, F. *Fertilizer Applications with Drip Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 411-415. July 1974.

It has been found that the applications of fertilizer mixtures through a drip irrigation system is not only feasible, but can be very beneficial. Fertilzer mixtures must not cause blockage, must be water suluble, must leave no residue in the fertilizer dispenser, and must be easy to handle.

61. Grossi, P. *Researches and Applications on Drip Irrigation and Similar Methods in Italy.* Proceedings of the Second International Drip Irrigation Congress, pp. 46-51. July 1974.

Research progress with trickle irrigation is discussed along with the hydraulic, pedological, and agronomical results of this research.

62. Gustafson, C.D., Marsh, A.W., Branson, R.L., and Davis, S. *Drip Irrigation - Worldwide.* Proceedings of the Second International Drip Irrigation Congress, pp. 17-20. July 1974.

Water is a precious commodity. Good water supplies are always in demand. All around the world, problems with water are: short supply, poor quality and/or expensive. In reviewing the development of drip irrigation, it is apparent that the greatest interest is in areas where there is a problem with water supplies. Poor soils or steep terrain also encourages the use of drip irrigation. Drip irrigation is not new. It has been used for years. What is new, however, is its application to modern agriculture. On a commercial scale in the United States, it can be traced back to 1969-70. That was not the beginning, however, since many industries have been using some type of drip irrigation for a long time. Drip

irrigation had its beginning the the greenhouse culture after World War II in the United Kingdom. In the late 1950's and early 60's, Richard Chapin, New York; Dr. Symcha Blass, Israel; and Dr. Vollmer Hansen, Denmark, simultaneously were perfecting what is commonly known as the spaghetti system.

63. Gustafson, C.D., Marsh, A.W., Branson, R.L., and Davis, S. *Drip Irrigation Experiment on Avocados.* Proceedings of the Second International Drip Irrigation Congress, pp. 443-445. July 1974.

In June, 1970 an irrigation project was initiated to compare drip irrigation with the conventional spitter-sprinkler system, commonly used in avocado orchards. Evaluation of the two methods include: 1) a comparison of growth and productivity; 2) salinity accumulation and distribution in soils under each system; 3) annual costs to operate each system; 4) determine if trees are more or less susceptible to the avocado root rot desease; and 5) observe operation of equipment.

64. Hall, B.J. *Staked Tomatoe Drip Irrigation in California.* Proceedings of the Second International Drip Irrigation Congress, pp. 480-486. July 1974.

Six staked tomatoe drip irrigated filed trials, where properly grown, resulted in slightly higher yields and appreciable water savings, compared to furrow applications. Drip irrigation supplied water more uniformly which resulted in more even plant growth. Cultural operations can be carried out in the drip irrigated crops at any time, while close coordianation of these operations is essential when using furrow or sprinkler irrigations.

65. Hall, B.J. *Spring Cucumber Drip vs. Furrow Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 486-490. July 1974.

Two field trials conducted on the early spring cucumbers started and grown in plastic row covers indicate that drip irrigation can successfully produce good yields. Less water can be used in producing as high or better yields with drip irrigation. Slow release fertilizer resulted in good yeilds, yet the plants appeared to run short during the last two or three weeks. Placing the drip line in the bottom of a 1 1/2 to 2-inch narrow furrow appeared to reduce the mature fruit pressure on the drip lives in bush culture.

66. Hanson, E.G., and Patterson, T.C. *Vegetable Production and Water-Use Efficiency as Influenced by Drip, Sprinkler, Subsurface, and Furrow Irrigation Methods.* Proceedings of the Second International Drip Irrigation Congress, pp. 97-102. July 1974.

Sweet corn and onions have been grown on replicated plots with four methods of irrigation: drip, subsurface, sprinkler, and furrow. Half of the plots have been irrigated to maintain the soil moisture tension at or below 0.20 atmospheres, and the other half at or below 0.60 atmospheres. Yield, quality, and water-use efficiency pertaining to each crop is reported for three growing seasons. Changes in soil salinity are discussed.

67. Harrison, D.S., and Myers, J.M. *Drip Irrigation Design Criteria for Tree Crops in Florida and Other Humid Regions.* Proceedings of the Second International Drip Irrigation Congress, pp. 33-37. July 1974.

Drip irrigation has been installed on approximately 4,000 acres of citrus and other orchard crops in Florida during the past 2 years. Some of the reasons for increased interest in this method of irrigation are: (1) conservation of water, (2) labor savings, (3) lower operating costs, and (4) lower power requirements. Some problems have developed and the future of drip irrigation in Florida will depend on how those problems are dealt with. Among significant problems are: (1) improper water filtration, (2) research data on crop response not readily available (3) vandalism, (4) unavailability of fully tested design criteria, (5) emitter spacing, and (6) expected life. Two years research data in Florida on strawberries, and one year on tomatoes show that response to drip irrigation is comparable to other application emthods and water savings as much as 60-70 percent may be expected. Fertilizer response, when applied through the drip system, has been outstanding.

68. Hiler, E.A., and Howell, T.A. *Crop Response to Trickle and Subsurface Irrigation.* American Society of Agricultural Engineers, Paper No. 72-744. 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 incerase 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 3 levels of trickle irrigation amounts in 1972 indicated that water-use efficiency increased by 50 percent with sparing trickle applications.

69. Hiler, E.A., and Howell, T.A. *Grain Sorhyum Response to Trickle and Subsurface Irrigation.* Transactions of the American Society of Agricultural Engineering, Vol. 16, No. 4, pp. 799-803. 1973.

Grain sorghum was grown during 1971 and 1972 in a field lysimeter installation in which control of the soil water could be maintained. Undisturbed soil cores approximately one meter in diameter and two meters deep made up the lysimeters. Rainfall was kept off the lysimeters with an automated shelter system. Irrigation treatments during 1971 included subsurface, trickle, subsurface plus mist, trickle plus mist, mist, and surface. All treatments involving subsurface and trickle irrigation were irrigated every third day in an amount calculated to bring the soil water content to "field capacity." The mist treatment was "overmisted" slightly so that the soil water potential would be maintained between 0 and -0.7 bar. The surface treatment was irrigated when the soil water potential in the root zone reached -0.7 bar in the amount of 1.1 times measured depletion.

70. Hoare, E.R., Garzoli, K.V., and Blackwell, J. *Plant Water Requirements as Related to Trickle Irrigation.* Proceedings of the Second International Drip Irrigaiton Congress, pp. 323-328. July 1974.

Trickle irrigation differs from spray and flood irrigation in that water is supplied in small amounts at frequent intervals in order to satisfy, as closely as possible the plants' immediate needs. This is in contrast to other forms of irrigation in which large quantities of water are supplied, following which a gradual drying of the soil takes place, and subsequent irrigation is carried out to replenish the reservoir of soil moisture. The difference in these two approaches to irrigation means that current methods of estimating the water requirements of crops requires further evaluation. Not only does the water requirement vary with different climatic conditions, age of the plants and the season, irrespective of the method of irrigation, but the use of trickle irrigation imposes a further variation due to its particular effect on the soil-plant-atmosphere complex. The water requirements of plants under trickle irrigation are examined and ways are suggested in which these may be calcualted from evaporation data, soil properties and other characteristics specific to the particular crop. Reference is also made to the use of trickle irrigation in particular situations, and how the water requirements in such cases can best be satisfied.

71. Hoffman, G.J., Rawlins, S.L., Oster, J.D., and Merrill, S.D. *Salinity Management for High Frequency Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 372-375. July 1974.

A field plot experiment designed to determine the minimum leaching required to maintain crop yields under high frequency irrigation is described. Two varieties of wheat, grain sorghum, and lettuce are being grown in rotation each year in six replicated leaching fraction treatments. Precise measurements of the volume and salt concentration of the irrigation and drainage waters along with in situ soil salinity measurements and corp yield are reported.

72. Howell, T.A., and Hiler, E.A. *Trickle Irrigation System Design.* American Society of Agricultural Engineers, Paper No. 72-221. 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. Systems 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. Peak 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 overdesign, requiring application of practical experience. Experimental verification of pressure distribution predicted by the computer has not been conducted.

73. Howell, T.A., and Hiler, E.A. *Trickle Irrigation Lateral Design.* Transactions of the American Society of Agricultural Engineers, Vol. 17, NO. 5, pp. 902-908. 1974.

A design method for determining the pressure loss and emitter flow ratio for trickle irrigation laterals is presented. The design method is based upon known principles of fluid mechanics. A computer program was written to determine the lateral pressure loss and emitter flow ratio at a given design length as a function of pipe size, tree spacing, number of emitters per tree, emitter spacing, downstream lateral pressure, and lateral slope. For a given set of design inputs, the program can be used to determine if the given pipe size will be adequate to limit the pressure loss and flow variation along the lateral to limits acceptable for the design lateral length.

74. Howell, T.A., and Hiler, E.A. *Designing Trickle Irrigation Laterals for Uniformity.* Proceedings of the Second International Drip Irrigation Congress, pp. 299-304. July 1974.

Proper design of trickle irrigation laterals for desired uniformity is important to prevent under-irrigation, with resulting crop damage, or over-irrigation, with resulting water losses of drainage and runoff. Recently several papers have presented trickle irrigation design data and methods; yet a simple design equation for directly determining maximum lateral lengths for different lateral slopes, trickle emitter types, pipe sizes, and desired uniformity is not available. Design equations, based on standard principles, fluid mechanics, and graphs are presented which can be used to determine maximum trickle irrigation lateral lengths for selected uniformities. The maximum lateral length for a given uniformity is given as a power function (linear log-log) of either emitter spacing or number of emitters per lateral. Engineering design aplications for this method are given in the form of specific examples. Implications and assumptions inherent in the method are discussed.

75. Hundtoft, E.B., and Wu, I.P. *Continuous Function Designs for Demonstration and Research.* Misc. Publication 115, Cooperative Extension Service, University of Hawaii. April 1974.

All other factors being equal, the effects of growth-influencing variables are smooth and continuous. A slight change in any factor will cause but a slight response in growth neglecting extreme levels near the thresholds of total absence or lethality. Graphically, yield as a function of two variables is readily interpreted as a surface over a two-dimensional coordinate system. Contours of constant response are identically interpreted as contours of constant elevation on topographical maps. The peak of a hill corresponds to the coordinates (or conditions) of maximum yield.

76. Isobe, M. *Fertilization with Drip Irrigation for Sugarcane.* Cooperative Extension Service, University of Hawaii Miscellaneous Publication No. 104, pp. 19-23. April 1973.

Drip irrigation for sugarcane offers a highly effective method for distributing fertilizer to the crop. The application of plant nutrients by water is not new--it has been used in surface irrigation for a long time and experimentally with sprinklers--but the drip method is more attractive for several reasons. Fertilizer application through the drip system often results in lower cost of application and possibly higher use efficiency.

77. Isobe, M. *Investigations in Sugarcane Fertilization by Drip Irrigation in Hawaii.* Proceedings of the Second International Drip Irrigation Congress, pp. 405-410. July 1974.

Research was initiated in Hawaii to determine efficient ways to fertilize sugarcane under drip irrigation. Paper reports on improvement of fertilizer efficiency and the use of aqua ammonia, the cheapest source of nitrogen available on the market.

78. Jensen, M.E., Robb, D.C.N., and Franzoy, C.E. *Scheduling Irrigations Using Climate-Crop-Soil Data.* Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, Vol. 96, No. IR1, pp. 25-38. 1970.

The most important factor affecting irrigation efficiencies and crop yields is scheduling irrigations in time and amount. Over-irrigation may result in waterlogged soils, a condition which reduces yields and generally results in increased costs for water, fertilizer, and drainage. Water used is at a minimum when the amount of water applied is just equal to the consumptive use and the leaching requirement. To achieve higher irrigation efficiencies, present irrigation scheduling practices must be improved. Irrigation scheduling using climate-drop-soil data, computers to facilitate the tedious computations, and field observations by experienced personnel is a service that appears to be very attractive to the modern irrigation farm manager. This service has the potential of increasing the management skills of the farmer and his net return at a reasonable cost. It supplements the art of irrigation or experienced judgement with the results of recent advances in irrigation science.

79. Jonas, S., and Rapp, E. *Trickle Irrigation in Alberta.* Agriculture Bulletin, University of Alberta, No. 23, pp. 15-19. Spring 1974.

The objective of trickle irrigation is to maintain an adequate portion of the plant root zone at the field capacity moisture level during the growing season. This is achieved by continual release of drops of water from small orifices. A comparison of water quantities applied during the 1973 growing seasons with various irrigation methods is presented. Crops grown were tomatoes, carrots, cucumbers, and strawberries.

80. Karmeli, D., and Keller, J. *Evaluation of a Trickle Irrigation System.* Proceedings of the Second International Drip Irrigation Congress, pp. 287-292. July 1974.

Factors determining performance of the system i.e., filtration quality, pressure and soil moisture distributions, are analyzed. Techniques for the evaluation of a system design or field performance are described and an equation to calculate the emission

uniformity, EU, of a trickle system are presented. Results of field tests and design evaluations are summarized and criteria established. Relationships between EU and soil volume values as well as irrigation regimes (application rates and intervals) are discussed.

81. Keller, J., and Karmeli, D. *Trickle Irrigation Design Parameters.* American Society of Agricultural Engineers, Paper Number 73-234. June 1973.

Paper consists of basic definitions, objectives of trickle, advantages and disadvantages. Formulas for computation of irrigation depth and interval, flow rates through emitters, system capacity, flow characteristics for various emitters, and emission uniformity (EU) are all presented. Lateral and manifold design are presented along with an example of system layout with complete design figures.

82. Keller, J., and Karmeli, D. *Trickle Irrigation Design for Optimal Soil Wetting.* Proceedings of the Second International Drip Irrigation Congress, pp. 240-245. July 1974.

The general relationship between the percentage area wetted and crop productivity is discussed and the recommended trickler spacing for achieving the desired soil wetting is presented. The number of operating blocks (stations or subunits) required to obtain the desired soil wetting is developed considering ET demands and system capacity constraints. The effect of the number of blocks on hydraulic features of the network and the relative economic effect is considered.

83. Keller, J., and Karmeli, D. *Trickle Irrigation Design.* Rain Bird Sprinkler Manufacturing Corporation, Glendora, California. 1975.

This text provides a rather complete review of trickle irrigation with sufficient handbook material and instruction for system design. It has been written with the student engineer, research and adviser, as well as existing and potential users, in mind. To enhance its usefulness, this text is written with both metric and English units of measurement.

84. Kenworthy, A.L. *Trickle Irrigation...The Concept and Guidelines for Use.* Research Report No. 165, Agricultural Experiment Station, Michigan State University, East Lansing. 1972.

Trickle irrigation is based on the concept that the best use of available water resources and best plant performance may be realized through preventing moisture stress (as opposed to correcting

moisture stress) by maintaining favorable soil moisture conditions on only a portion of the root system. Water is applied under low pressure (15 lb or less) and at slow rates (1 to 2 gallons per hour) for a sufficient period of time to maintain part of the soil at or near field capacity. A trickle system should be designed to provide equal delivery of water from all emitters after considering pressure, friction or line loss, elevation changes and any other factor that influences flow of water.

85. Kenworthy, A.L. *Trickle Irrigation...Simplified Guidelines for Orchard Installation and Use.* Agricultural Experiment Station, Michigan state University, Research Report 248. May 1974.

Continued research using new techniques and material has simplified installation of trickle irrigation systems. The use of flow regulating valves, grommets for inserting microtubes, and other methodology are discussed.

86. Kenworthy, A.L., and Kesner, C. *Trickle Irrigation in Michigan Orchards: Controlling Rate of Flow with Flow Regulating Valves and Microtubes.* Proceedings of the Second International Drip Irrigation Congress, pp. 275-280. July 1974.

An appropriate combination of flow regulating valves and microtubes of different inside diameter has been found ideal for studying rates of flow in trickle irrigation. The flow regulating valve is installed in a row lateral. Capacity of the valve is selected to provide the amount of water desired for the row. To distribute the water and counter elevation changes, microtubes of different inside diameters are used and thus avoid excessive micro-tube lengths. Selection of an appropriate microtube ID in accordance to flow rate will permit a uniform value to adjust micro-tube length according to elevation change. Data on uniformity of water distribution are presented.

87. Kesner, C.D., and Kenworthy, A.L. *Trickle Irrigation in Michigan Orchards.* Proceedings of the Second International Drip Irrigation Congress, pp. 272-273. July 1974.

The concept of trickle irrigation is being rapidly accepted by Michigan fruit growers. A major source of water is from small existing wells previously used for cooling sour (red tart) cherries at harvest time and other purposes. Lakes, ponds, rivers and creeks also serve as water sources. Pressure regulators or gate valves were origianlly used to control in-line pressure but the present trend is toward flow regulating valves in each row lateral. The primary emitter system in Michigan is the microtube with .025, .035, .036, or .045 in I.D. tubes being the most popular. An illustrated presentation demonstrates the techniques used in may different installations.

88. Lange, A., Aljibury, F., Fischer, B., Humprey, W., and Otto, H. *Weed Control Under Drip Irrigation in Orchard and Vineyard Crops.* Proceedings of the Second International Drip Irrigation Congress, pp. 422-424. July 1974.

Conventional herbicide applications in orchards and vineyards under drip irrigation have been somewhat unsuccessful. Annual applications of most herbicides have broken down in the moist area close to the dripper leaving a vigorous small circle of weed growth by summer. Herbicides differ in their rates of breakdown under drip irrigation when compared to furrow and sprinkler. Atrazine showed the greatest response to breakdown under continuously wet soils. Napropamide was affected least by wet soils. Trifluralin, profluralin, and norflurazon were intermediate. Numerous herbicide treatments have been evaluated under drip irrigation. The results of several of these are discussed.

89. LaRue, M.E. *Experience in Drip Irrigation.* Proceedings of the Subsurface and Drip Irrigation Seminar, University of Hawaii, Miscellaneous Publication No. 102., pp. 25-27. January 1973.

Article discussed the author's experiences in drip irrigation including filtration of water and fertilization through the system.

90. Levin, I., Assaf, R., and Bravdo, B. *Soil Moisture Distribution and Depletion in an Apple Orchard Irrigated by Tricklers.* Proceedings of the Second International Drip Irrigation Congress, pp. 252-257. July 1974.

Four treatments of trickle irrigation methods were applied in an apple orchard on heavy soil. The treatments differed in water discharge rate of the tricklers (4 and 8 liter/hour), distances between the outlets on the lateral lines (1.25 m and 2 m) and irrigation frequency (1, 3 and 7-day intervals). In all treatments the amount of water applied was on the basis of 10 mm/day consumptive use. Soil moisture content fluctuations in the upper 60 cm layer before, during and after irrigation were frequently measured. The distance wetted from the trickler was linearly dependent on the duration of the single irrigation and the discharge rate of the trickler; 65 cm, 80 cm, and 120 cm after 14, 24 and 70 hours of irrigation at a 4 liter/hour discharge rate, respectively; and 120 cm after 40 hours at a 8 leter/hour discharge rate. The soil moisture content at the end of the irrigation dropped gradually from under the trickler to the farthest distance wetted, where about 90 percent of field capacity was reached. After the temination of the irrigation, the soil moisture content depleted gradually to the level before the beginning of the irrigation--at all distances from the tricklers and in all treatments. The results indicate that there was deep drainage below the root zone in the area under the tricklers in all treatments.

91. Lindsey, K.E., and New, L.L. *Application of Fertilizer Through Drip Irrigation Systems in West Texas.* Proceedings of the Second International Drip Irrigation Congress, pp. 400-404. July 1974

Zinc chelate applications to pecan trees were made through several types of systems on several soil types. Comparisons were made with customary spray applications of Zn. Effectiveness of applications was measured by leaf analysis and trunk growth measurements. Examination of the effectiveness of several of the injection systems was done by analyzing water emitted at timed intervals after injection of Zn materials.

92. Lombard, P.B. *Pear Tree Response to Trickle Irrigation on Carney Clay Soil.* Drip Irrigation Rsearch in Oregon, Agricultural Experiment Station, Oregon State University, Special Report 412. April 1974.

A trickle irrigation system was installed on one acre of fourth-year years and performance of the system and plant response was compared to that of an adjacent furrow irrigated planting. Water applications were designed to apply to the area within the tree's drip line an amount equivalent to that lost by a standard U.S. Weather Bureau evaporation pan.

93. Lomen, D.W., and Warrick, A.W. *Time-Dependent Linearized Infiltration: II. Line Sources.* Soil Science Society of America Proceedings, Vol. 38, No. 4, pp. 568-572. 1974

Water flow from line sources is analyzed using a linearized form of the moisture flow equation. Both single and parallel line sources are considered. Results are particularly relevant for high-frequency irrigation, such as by trickle sources, for which the soil moisture at any particular point varies over a relatively small range. Numerical calculations include lines of constant matrix flux potential (or equal moisture content) as a function of time and the time-dependent response to a cyclic input. Although the results are developed for surface sources, the analysis may easily be extended to buried sources.

94. Manfrinato, H.A. *Effects of Drip Irrigation on Soil-Water-Plant Relationship.* Proceedings of the Second International Drip Irrigation Congress, pp. 446-451. July 1974.

Soil columns, prepared in the laboratory, by packing sieved and air dried soil into cylinder tubes were used to study the distribution of moisture content at the moment of infiltration. Drops of water, were applied simulating rain, at eight different intensities, called treatments, with two repetitions. When the water application rate was continually reduced throughout the treamtents, the moisture content also diminished and vice versa. It was also concluded that when the rain application intensity was

decreasing to a very small rate, the moisture content had such a slow reduction, as if going to a limit, which was found to be the soil field capacity.

95. Marsh, A.W., Branson, R.L., Gustafson, D.C., and Davis, S., *Drip Irrigation.* University of California Agricultrual Extension, OSA #N59. 1972.

Drip irrigation is the frequent slow application of water to soil through mechanical devices calle emitters located at selected points along water delivery lines. The application rate must be slow enough so that the runoff in the usual sense does not occur. Most of the movement of water to wet the soil between emitters occurs by capillarity beneath the soil surface.

96. Marsh, A.W., Gustafson, C.D., Davis, S., Branson, R.L., and Strohman, R.A. *Water Use by Drip and Sprinkle Irrigated Avocados Related to Plant Cover, Evaproation and Air Temperature.* Proceedings of the Second International Drip Irrigation Congress, pp. 346-350. July 1974.

Water application to the avocados has been closely controlled by relating it to tensiometer readings. A sufficiency has been maintained while limiting excesses. In 1973, the drip applications have been automatically controlled by electrified tensiometers that provide signals for a controller. The measured applications are thought to represent the actual water requirement for each irrigation system as closely as it can be determined. The correlation of measured water use to evaporation from a class A pan is shown for each irrigation method as influenced by varying air temperature, percentages of plant cover, and period of the year.

97. Martin, D.J. *Drip Irrigation Systems.* Proceedings of the Subsurface and Drip Irrigation Seminar, University of Hawaii, Miscellaneous Publication No. 102, pp. 5-7. January 1973.

Filtering system has presented the largest problem. Sane, yak (open screen), pressure cartridge, and cyclone filters are under study. The yak screen in combination with a sand filter might be a good combination.

98. Martin, L.W., Shearer, M.N., and Kangas, K.F. *Use of Pan Evaporation as a Guide to Scheduling Drip Irrigation in Blackberries.* Drip Irrigation Research in Oregon, Oregon State University, Special Report 412. April 1974.

A drip irrigation system was installed in a mature planting of "Thornless Evergreen" blackberries and performance of the system and plant response were compared to that in an adjacent planting irrigated with solid-set sprinklers.

99. McElhoe, B.A., and Hilton, H.W. *Chemical Treatment of Drip Irrigation Water.* Proceedings of the Second International Drip Irrigation Congress, pp. 215-220. July 1974.

Bacteria and other microorganisms in water are contributors to orifice plugging. Their skeletons, the slimes they produce, and their metabolic products are the glue that binds fine soil particles to the walls of the tube. Chemical treatment can arrest the agglomeration process and significantly reduce plugging.

100. Mehdizadeh, P., and Tamaddoni-Jahromi, S. *An Investigation on the Use of Drip Irrigation for the Establishment of Multi-purpose Parks (Green Belts Around the Cities) in Iran.* Proceedings of the Second International Drip Irrigation Congress, pp. 462-468. July 1974.

Paper deals with the application of a "home made" drip irrigation system in a multipurpose forest park near Tehran. The study was initiated as a pilot trial to determine: (1) if drip irrigation should be considered for irrigating forest species in the parks and green belts of Iran, (2) plant responses to drip irrigation of green belts, and (3) possible water savings. Although some suppression of height growth was found, seedlings remained healthy. The amount of irrigation water used was reduced by 85 percent as compared to the furrow irrigation system used previously.

101. Mellentin, W.M., Kelly, S., and Wang, C.Y. *Trickle Irrigation Progress Report in the Mid-Columbia Area.* Drip Irrigation Research in Oregon, Agricultural Experiment Station, Oregon State University, Special Report 412. April 1974.

The objective of the current project underway at the mid-Columbia Experiment Station is to obtain information on problems during the transition from sprinkler applications to trickle systems on bearing pear trees.

102. Middleton, J.E., Proebsting, E.L., Roberts, S., and Emerson, F.H. *Tree and Crop Response to Drip Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 468-473. July 1974.

Bearing "Early Italian" prune trees performed normally with 60 and 80 gallons per tree per day using continuous drip irrigation. With 20 and 40 gallons per tree per day the fruit was smaller, better colored and earlier with higher soluble solids. In the second year, the two lower rates greatly reduced bearing surface and yields. Leaf moisture data indicated no difference in the four quadrants of the tree when all water was applied at one point.

Twelve hour daily applications were compared to continuous applications the second year. There were some soluble salts in the non-saline soil which were reduced measurable by movement away from the center of the drip area as the season progressed. Soil moisture movement was recorded. Growth response of first year apple trees to drip and sprinkler irrigation at comparative application frequencies and amounts was similar.

103. Mitchell, P.D., and Black, J.D.F. *Trickle Irrigation on Young Peach Trees.* Proceedings of the Second International Drip Irrigation Congress, pp. 452-455. July 1974.

Two field trails on young peach trees are described.
Trial A. The effects of supplying 9, 18, 36, or 72 l of water per day to newly planted peach trees regardless of rainfall and evaporation demonstrate that these factors cannot be ignored in soils of imperfect drainage. Trees died under the highest rate, were severely damaged at the second highest rate, showed some root damage under the second lowest rate but grew better at this rate than at the lowest rate.
Trial B. Growth of peach trees trickle irrigated daily or after 2.5 or 5 cm net evaporation intervals are compared. Response was less at the 5 cm interval than at the 2.5 cm or daily intervals. Root density in the wetted root zone was highest under the daily interval and least under the 5 cm interval. A significant linear relationship is established between trunk area increase and water applied per unit of trunk are per unit of evaporation. The treatment limit in this trial of 2.5 l per sq. cm. trunk area per cm evaporation is to be extended in further trials.

104. Mitchell, W.H., McIlvaine, J.E., and Mueller, J.P. *Subsurface Irrigation with Perforated Plastic Tubing.* Agricultural Extension Service, University of Delaware, Bulletin No. 99. 1969.

Irrigation systems are changing as the demand grows for automated units requiring a minimum of labor and designed to make efficient use of water. Research has shown that subsurface irrigation using perforated plastic tubing meets many of the requirements of a practical and efficient system. Evaluation and developmental work on subsurface irrigation conducted during a four year period by the Delaware Agricultural Extension Service is reported.

105. Myers, L.E., and Bucks, D.A. *Uniform Irrigation with Low-Pressure Trickle Systems.* Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers. September 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 emitters suffer from nonuniformity 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 computation and graphic method were developed.

106. Nelson, S.D., and Davis, S. *Soil Salinity Distribution in Sprinkler - and Subsurface - Irrigated Citrus.* Transactions of the American Society of Agricultural Engineers, Vol. 17, No. 1, pp. 140-143. 1974.

Soil salinity distribution produced by subsurface irrigation results in maximum salt concentrations at the perimeter of the wetting front. The soil salinity increases most in the soil above the burial depth of the subsurface pipe. Winter rainfall could be effectively used to leach accumulated surface salts from the root zone of subsurface - irrigated citrus in southern California, by maintaining a high water content during the rainfall months, allowing precipitation to be used only for leaching and not for increasing the soil water content. By using this management method, a more favorable salt balance was maintained.

107. New, L., and Roberts, R. *Automatic Drip Irrigation for Greenhouse Tomato Production in West Texas.* Proceedings of the Second International Drip Irrigation Congress, pp. 159-164. July 1974.

Soil moisture sensors are used to automatically control the operation of drip irrigation systems and maintain optimum moisture levels in West Texas tomato greenhouses. Up to ten thousand square feet of growing area is being successfully irrigated by one sensor. Time clocks cause intermittent irrigation which helps prevent overwatering, puddling and runoff. Water flow control valves limit drip emitter water application rates to 1.0 to 1.5 gallons per hour.

108. Noyola, F.T. *A Study on Different Application Procedures of Drip Irrigation in Tomato Cultivation.* Proceedings of the Second International Drip Irrigation Congress, pp. 508-511. July 1974.

Article discusses results of a study on tomatoes to determine reasonable application procedures of drip irrigation water.

109. Paldi, H. *Drip Irrigation and Automation Tools in Efficient Use of Water Policy.* Proceedings of the Second International Drip Irrigation Congress, pp. 29-32. July 1974.

Article discusses water savings in Israel with drip irrigation, long range irrigation plans for Israel, and irrigation system automation.

110. Parchomchuk, P. *Filters for Trickle Irrigation.* Canadian Department of Agriculture Research Station, Summerland, British Columbia. October 1973.

Article discusses sand filters, cartridge filters, screen filters, bag filters, and fiberglass insulation filters along with the advantages and disadvantages of each.

111. Patterson, T.C., and Wierenga, P.J. *Influence of Trickle Irrigation on Irrigation Return Flow.* American Society of Agricultural Engineers, Paper Number 73-2506. December 1973.

Deterioration of water quality in the Rio Grande as a result of irrigation along the stream, is a major problem for water users in New Mexico and Texas. A research project designed to determine, under field conditions, rates of water and salt movement under surface and trickle irrigation is described.

112. Patterson, T.C., and Wierenga, P.J. *Irrigation Return Flow as Influenced by Drip Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 376-381. July 1974.

Deterioration of water quality in the Rio Grande is a major problem for water users in New Mexico and Texas. From near Santa Fe, New Mexico to El Paso, Texas, a distance of 270 miles, the total of dissolved solids increases from 221 ppm to 787 ppm while the percent of sodium increases from .25 near Santa Fe to 52 at El Paso. The deterioration in quality is due to the return of lower quality drainage water from the irrigated areas to the river. This paper describes a project designed to determine, under field conditions, rates of water and salt movement in the soil and subsequently to the drains as affected by frequency and amount of trickle irrigation, as compared to frequency and amount of surface water application. Both return flow quality and quantity are evaluated.

113. Pelleg, D., Lahav, N., and Goldberg, D. *Formation of Blockages in Drip Irrigation Systems: Their Prevention and Removal.* Proceedings of the Second International Drip Irrigation Congress, pp. 203-208. July 1974.

Clogging is one of the most severe problems associated with trickle irrigation systems. The different kinds of clogging are described along with the reasons for clogging. Methods of preventing clogging are given, and ways of cleaning systems after clogging has occurred are discussed.

114. Phene, C.J. *High-Frequency Porus Tube Irrigation For Water-Nutrient Management in Humid Regions.* Proceedings of the Second International Drip Irrigation Congress, pp. 166-171. July 1974.

A plastic porous tube and an electronic soil matric potential sensor supplied sweet corn with nutrients and water automatically by controlling the water content of a limited volume of root-zone soil. Sweet corn yield and water-use efficiency obtained with high-frequency porus tube irrigation systems were compared with those obtained from high-frequency sprinkler and furrow irrigation systems under similar irrigation control and fertility. In another experiment, sweet corn yield, plant nitrogen uptake, and soil NO3(-) movement were studied under controlled soil matric potential for various application rates of N and K. Ear yield with high-frequency porus tube irrigation was 10.5 and 12.6% greater than ear yield obtained with furrow and sprinkler irrigation, respectively. Water-use efficiency was 37 and 54 percent higher for sensor controlled high-frequency porus tube irrigation than for furrow and sprinkler irrigation.

115. Phene, C.J., Hoffman, G.L., and Austin, R.S. *Controlling Automated Irrigation with Soil Matric Potential Sensor.* Transactions of the American Society of Agricultural Engineers, Vol. 16, No. 4, pp. 773-776. 1973.

The successful use of a soil matric potential sensor to control automatic irrigation has been demonstrated in both the laboratory and the field. The soil matric potential in a soil-plant system was controlled automatically at -0.15 ± 0.01 bar in the laboratory when the system was subjected to variable temperatures. Irrigations were also controlled automatically at -7.6 ± 0.5 bars in a soil-plant system. In the field, the soil matric potential at the 15-cm depth was automatically controlled at -0.21 ± 0.05 bar and -0.27 ± 0.03 bar in plots planted to sweet corn. The fluctuation of the soil matric potential measured could have been further reduced by increasing the duration of water application at each irrigation. This in no way reflects on the capability of the sensor to control the irrigation system. The sensor called for irrigation when water was needed.

116. Pira, E.S. *Chamber Method for Drip Irrigation System Design and Installation Procedure.* Proceedings of the Second International Drip Irrigation Congress, pp. 121-126. July 1974.

High pressure water is supplied through a "quick-fill" and pressure reducing device to a low pressure chamber. A minimal pressure drop in the chamber produces a relatively uniform discharge rate from the drippers. This paper deals with the practical field installations based on laboratory tests, field tests and simulation model. System design criteria, components, materials, detailed illustrations and installation procedures are presented.

117. Pira, E.S., and Purdhit, K.S. *Operating Characteristics and Design Criteria for the Chamber Method of Subsurface and Drip Irrigation Systems*. American Society of Agricultural Engineers, Paper No. 72-226. June 1972.

By varying cross sectional area and length of the low pressure distribution line (chamber) uniform discharge rates can be produced through the emitters. Discharge rates can be changed by adjusting chamber pressure. "Quick-fill" is necessary to make the system practical. In other words, the chamber must be charged with water before good operation begins. Field installation in an apple orchard is discussed.

118. Raats, P.A.C. *Steady Infiltration From Line Sources and Furrows*. Soil Science Society of America Proceedings, Vol. 34, pp. 709-714. 1970.

Steady infiltration from an array of equally spaced line sources of furrows at the surface of a semi-infinite soil profile is analyzed. The discussion is based on the assumption that the hydraulic conductivity is an exponential function of the pressure head. It is shown that, under this assumption, the matric flux potential and the stream function for plane flows satisfy the same linear partial differential equation. Explicit expressions for the stream function, the flux, the matric flux potential, the pressure head, and the total head are obtained. Some implications with regard to furrow irrigation are discussed. The solution provides a rational basis for the discussion of leaching under furrow irrigation.

119. Raats, P.A.C. *Steady Infiltration From Point Sources, Cavities, and Basins*. Soil Science Society of America Proceedings, Vol. 35, pp. 689-694. 1971.

Steady infiltration from buried point sources and surface point sources is analyzed. The partial differential equation for the matrix flux potential and the Stokes' stream function associated with axially symmetric flows are derived. The discussion is based on the assumption that the hydraulic conductivity is an exponential function of the pressure head. Explicit expressions for the matrix potential, the Stokes' stream function, the flux, the pressure head, and the total head are obtained. Some features of the solutions for buried point sources, surface point sources, and gravity-free flows are compared. Related upward flows for which the soil becomes saturated everywhere are discussed briefly.

120. Raats, P.A.C. *Steady Infiltration From Sources at Arbitrary Depth.* Soil Science Society of America Proceedings, Vol. 36, pp. 399-401. 1972.

This discussion of steady infiltration is based on the assumption that the hydraulic conductivity is an exponential function of the pressure head. The solution for infiltration from a single point source at arbitrary depth is presented. General expressions for the pressure head, the total head, and the components of the flux are also given.

121. Raats, P.A.C. *Movement of Water and Salts Under High Frequency Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 222-227. July 1974.

Many modern irrigation systems deliver water at short intervals, in space as well as in time. Theoretical analyses show that the remaining variations are damped rapidly. Consequently, steady, one-dimensional movement and uptake is used as a basis for further analysis. Qualitative features of possible steady pressure head and water content profiles are discussed. Specific calculations for various leaching fractions and amounts of capillary rise from a water table are based on empirical, but realistic models for the dependence of the hydraulic conductivity upon the pressure head and for the spatial distribution of the rate of uptake. The resulting salinity profiles are also calculated. The results are compared with earlier, more approximate calculations.

122. Rawitz, E., and Hillel, D. *The Progress and Problems of Drip Irrigation in Israel.* Proceedings of the Second International Drip Irrigation Congress, pp. 23-28. July 1974.

The "state of the art" of drip irrigation in Israel is reviewed regarding both equipment and operational practices. Equipment available on the market is generally reliable and conforms to manufacturer's specifications of hydraulic properties. Filtering and clogging of small discharge orifices remains a problem under certain conditions. A standard head has been developed for connection to the main system incorporating filter, vacuum breaker, fertilizer applicator, pressure regulator, and automatic valves. Hydraulically or electrically actuated automatic valves are used either singly or for sequential operation. Many growers have reported excellent results with drip irrigation of orchards, truck crops, and flowers. The relative advantages of drip irrigation are especially pronounced where relatively saline water must be used under extremely arid conditions. Criteria and recommendations have yet to be determined regarding irrigation frequency and application amounts in relation to emitter spacing and discharge, and percent of wetted area for different crops, soil profile characteristics, climatic conditions, and water quality. Some consequences of improper operation may be under-irrigation, excessive restriction of the root zone, and excessive leaching of water and nutrients below the rooting depth.

123. Rawlins, S.L. *Principles of Managing High Frequency Irrigation.* Soil Science Society of America Proceedings, Vol. 37, pp. 626-629. 1973.

The consequences of increasing irrigation frequency are explored taking into consideration the laws governing water flow in soil. As frequency increases, the waterholding capacity of the soil becomes less important because water is supplied as the plants require it. Soil water content, and therefore matric potential, are continuously high and only slightly dependent upon deep percolation rates. This makes the need for deep percolation to leach salts the only valid criterion for applying more water than the plants transpire. The need to apply extra water to those crops that require high soil water content is eliminated. Controlling the deep percolation rate rather than the soil water states requires measurements of flux rather than water potential as inputs for managing the quantity of water to be applied.

124. Rawlins, S.L. *Reverse Flushing Technique for Bi-Wall Drip Tubing.* Proceedings of the Second International Drip Irrigation Congress, pp. 209-211. July 1974.

Particles carried in the irrigation water first lodge in the inside orifices between the supply and emission chambers of biwall drip tubing. These can be effectively dislodged by briefly applying water at high pressure to the emission chamber. They can then be flushed from the supply chamber in the usual manner. Because the burst pressure of tubing varies inversely with its diameter, the small emission chamber can withstand considerably higher pressures than can the supply chamber. Results of tests using this technique are discussed.

125. Rawlins, S.L., Hoffman, G.J., and Merrill, S.C. *Traveling Trickle System.* Proceedings of the Second International Drip Irrigation Congress, pp. 184-187. July 1974.

Typical drip irrigation systems deliver frequent applications of small volumes of water by using a large number of small diameter orifices installed along tubes. The long lengths of tubes and large number of emitters required make drip irrigation costly for row crops. In addition, the small diameter of the orifices required to control water flow in such a system makes it susceptible to plugging and adds an additional filtration expense. We describe a traveling trickle system that circumvents both of these problems by controlling water application with a few large orifices moved along the row rather than with a large number of fixed location orifices. Results are presented from cost analyses for large-scale systems by converting standard pivot sprinkler irrigation systems.

126. Read, A.L., Pietsch, M.F., and Matheson, W.E. *Australian Vineyard Uses Sewage Effluent with Trickle Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 382-387. July 1974.

The Angle Vale Vineyard is located 32 kilometres north of Adelaide, South Australia. Supplementary irrigation is necessary for the growth of vines in the area. In 1970 Government legislation precluded the future use of water in the area and a decision was made to use sewage effluent from Adelaide which was the only supplementary irrigation available. The 40 hectare vineyard had trickle irrigation installed and has since been enlarged to 180 hectares. The effluent has a T.D.S. varying from 1,300 to 1,800 mg/l and a varying but high algal content. The paper describes the problems of filtration and growths within the pipelines and how these problems were overcome. Monitoring of soil conditions has been necessary to study the changes in soil salinity. Maximum salinities have occurred at the perimeter of the wetted zone, approximately 50 cms from the vine rows. Total soluble salts have increased from 0.035% in the centre of the vine rows to 0.086-0.109% at the perimeter of the wetted zones. Analyses of the vine leaves and wine made from the first vintage are also reported.

127. Rolston, D.E., Ravschkolb, R.S., and Hoffman, D.L. *Use of Glycerophosphate for Fertilization Through Trickle Irrigation Systems.* Proceedings of the Second International Drip Irrigation Congress, pp. 416-421. July 1974.

There is little doubt after 60 years of scientific investigation with several sources of inorganic phosphate that phosphorus moves very little from point of contact with the soil. The greatest successes in measuring increased movement of phosphorus in the soil profile have occurred with organic forms of phosphorus. The development of new cultural management techniques such as trickle irrigation make the use of a water-soluble, non-corrosive, high analysis source of organic phosphorus an especially desirous material. A material with this capability would be of great value where trickle systems make it extremely difficult to achieve placement by mechanically injecting phosphorus below the soil surface. The movement and sorption of glycerol phosphate was studied in unsaturated soil columns during steady-state displacement of a fertilizer pulse. Fertilizer pulses equivalent to 90 kg/ha application rates were displaced at flow rates between 5 and 15 cm/day. Results demonstrate that glycerol phosphate is capable of being displaced to much greater depths than inorganic forms of phosphorus fertilizer. It is expected that glycerol phosphate can be applied through a trickle irrigation system and be distributed within the wetted root zone.

128. Roth, R.L. *Soil Moisture Distribution and Wetting Pattern From a Point Source*. Proceedings of the Second International Drip Irrigation Congress, pp. 246-251. July 1974.

Soil moisture distribution and wetting pattern tests were conducted using a point source on virgin desert sandy soil. The purpose of these studies was to characterize the extent of moisture movement and distribution within the wetted volume. The flow rates tested were approximately 3.8, 7.6, and 15.2 liters per hour (1, 2, and 4 gph) for durations of 1, 3, 6, 12, 24, and 48 hours. At the completion of each test, a pit was dug which exposed the maximum vertical diametral plane of the wetted volume. Measurements were made to define the maximum wetted area. Soil moisture measurements were made at each node point of a 15.2-centimeter (6-inch) grid imposed on the maximum wetted area. Soil cores were taken at 15.2-centimeter intervals along the line of maximum horizontal water movement. These cores were used to determine bulk density, soil texture, permeability, and moisture release characteristics. A complete soil profile description was also made of each test site. For the tests conducted the total volume of soil wetted was more a function of the amount of water applied than time of application. Maximum horizontal movement was greater than maximum vertical movement for volumes of water less than 190 liters (50 gallons). Greater maximum vertical movement occurred at volumes of water more than 190 liters. Water within the wetted volume was determined to be at tensions between 100-140 centimeters of water.

129. Roth, R.L., Rodney, D.R., and Gardner, B.R. *Comparison of Irrigation Methods, Rootstocks, and Fertilizer Elements on Valencia Orange Trees*. Proceedings of the Second International Drip Irrigation Congress, pp. 103-108. July 1974.

A 4-hectare (10-acre) block of 'Campbell' valencia orange trees planted in May 1971, was used to compare 5 irrigation methods, 2 types of rootstocks, and a phosphate and micronutrient variable. The irrigation methods were border, full-coverage sprinklers, limited-coverage sprinklers, basin, and trickle. Maximum tree growth, as measured by increase in trunk circumference, was achieved from the trickle and basin irrigation methods, even though these methods used approximately one-twentieth the water as compared to the normal border irrigation method. The full-coverage sprinkler method restricted tree growth due to salt injury of the leaves. Nitrate and salt concentrations in the root zone were mapped for each irrigation method. No observable effects of the fertilizer variables have been detected at this time.

130. Rubin, J. *Numerical Method for Analyzing Hysteresis Affected, Post-Infiltration Redistribution of Soil Moisture.* Proceedings of the Soil Science Society of America, Vol. 31, pp. 13-20. 1967.

An especially devised numerical procedure applied to the Darcian model of soil moisture flow makes it possible to analyze the post-infiltration redistribution of water in semi-infinite vertical soil columns. The method takes into account the effects of hysteresis by making it possible to find, within the hysteretic system of curves, the unique curve which characterizes moisture transformations at each soil depth. The method can be applied to cases in which the moisture flux at soil surface is zero as well as to those in which the redistribution is accomplished by constant-rate evaporation. The results obtained by applying the new method to data on moisture retention and conductivity of a sandy soil demonstrate the importance of hysteresis in the redistribution processes.

131. Schade, R.O. *The Use of Foggers in Drip Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 129-130. July 1974.

The rapid increase in drip irrigation in the United States has been accompanied by a large number of new products for its application. Most of this new equipment has been emitters of various types. These emitters are used to reduce the flow and to apply the water directly to the surface of the soil. In addition to emitters a device known as a fogger is also being widely used. The fogger as the name implies fogs or sprays the water into the air. The droplet size and output of each fogger ranges from 2 to 5 gallons per hour which is comparable to the discharge rate of most emitters being used today. Foggers have been installed on an estimated 8,000 acres. This accounts for approximately 15% of the acreage being irrigated by drip irrigation. Foggers are being used to irrigate citrus, decidious fruit, grapes, nuts and ornamentals. The area of principal usage at the present time is in the San Joaquin Valley of California.

132. Scott, S.R. *Erosion Control.* Proceedings of the Subsurface and Drip Irrigation Seminar, University of Hawaii, Miscellaneous Publication No. 102, pp. 39-41. January 1973.

Changes in cultural practices brought about by the switch in method of irrigation introduces some different erosion problems. Emphasis on improving the environment increases the importance of getting the practices on the ground which will do the job.

133. Seifert, W.J., Hiler, E.A., and Howell, T.A. *Trickle Irrigation with Water of Different Salinity Levels.* Transactions of the American Society of Agricultural Engineers, Vol. 18, No. 1, pp. 89-94. 1975.

Objectives of this study were (a) to determine effects of different concentrations of saline water on grain sorghum production and soil environment using trickle irrigation, and (b) to evaluate effects of irrigation water at one electrolyte concentration with both surface and trickle irrigation. The study was conducted in a sheltered lysimeter installation during two successive seasons. A norwood silt loam soil was utilized in the lysimeters. Salts were purposely not leached between seasons so that salinity buildup effects could be evaluated. Numerous crop, soil, and meteorological parameters were measured and evaluated to quantify effects of various treatments on the crop and soil.

134. Shani, M. *Trickle Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 91-96. July 1974.

Article presents advantages and disadvantages of trickle irrigation, types of emitters, filtration methods, and a discussion of fertilization techniques based on experience in Israel.

135. Shearer, M.N., Martin, L.W., Lombard, P.B. and Mellentin, W.M. *Interpreting Evaporation From Class A Weather Bureau Pan for Irrigation Scheduling of Crops Grown Under Trickle Irrigation.* Drip Irrigation Research in Oregon, Agricultural Experiment Station, Oregon State University, Special Report 412. April 1974.

A simple procedure for scheduling trickle irrigation of crops not completely covering all the soil surface with plant canopy was field tested at three experiment stations.

136. Shearer, M.N., Martin, L.W., Lombard, P.B., and Mellentin, W.M. *Drip Irrigation Research in Oregon - A Progress Report.* Proceedings of the Second International Drip Irrigation Congress, pp. 38-43. July 1974.

Drip irrigation research was initiated in Oregon in 1973. One year's results are reported on the following: (1) total yield, fruit size, water requirements, and mold incidence of cane fruit under drip and sprinkler irrigation, (2) total yield, fruit size, and water requirements of pears grown on low intake rate montmorillonite soils under drip and rill irrigation, (3) evaporation pan coefficients for scheduling drip irrigation, and (4) filtering requirements for irrigation water containing glacial silt and flour.

137. Shmueli, M., and Goldberg, D. *Emergence, Early Growth, and Salinity of Five Vegetable Crops Germinated by Sprinkle and Trickle Irrigation in an Arid Zone.* HortScience, Vol. 6, No. 6. December 1971.

Field experiments were conducted to test the emergence, early growth, and salt build-up in soil and leaves with 5 vegetable crops germinated by sprinkle and trickle irrigation using saline water. In some of the crops (cucumber, tomato, 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.

138. Shmueli, M., and Goldberg, D. *Sprinkle, Furrow, and Trickle Irrigation of Muskmelon in an Arid Zone.* HortScience, Vol. 6, No. 6, pp. 557-559. December 1971.

In a comparison of sprinkle, furrow, and trickle irrigation applied during the growing season from August to December to muskmelon, vegetative growth was found more rapid and yields were earlier and higher with the trickle method. No yield differences were detected between sprinkle and furrow irrigation. Salt accumulation on the leaves was greater with sprinkling than with the other 2 methods which do not wet the foliage. The chloride concentration in the leaves was also high throughout the entire growing season with sprinkle irrigation. Soil chloride content during the growing season varied according to the method of irrigation.

139. Shmueli, M., and Goldberg, D. *Response of Trickle-Irrigated Pepper in an Arid Zone to Various Water Regimes.* HortScience, Vol. 7, pp. 241-243. 1972.

Pepper plants were irrigated by trickling at a constant frequency of 1-2 days with 4 different amounts of water based on evaporation from a Class A pan. The amounts applied were 0.82, 0.95, 1.33, and 1.75 of the pan evaporation. An optimum curve was obtained for the relation between yield and water application, with the maximum yield resulting from use of the 1.33 factor. Determination of salt content in the soil and plants, and measurements of soil moisture showed that even the smallest water application was adequate to leach the root zone and to maintain a low and almost constant soil moisture tension. The optimum curve was found to be primarily due to a relatively small yield increase during the latter part of the harvest period when the potential evapotranspiration is increasing.

140. Singh, N.T., Grewal, S.S., and Josan, A.S. *Drip vs. Furrow Irrigation Trials in Potato Under Subtropical Conditions.* Proceedings of the Second International Drip Irrigation Congress, pp. 515-520. July 1974.

The drip method of irrigation was compared with conventional furrow irrigation in field grown spring and autumn potatoes. Treatments included irrigations at 0.25, and 0.50, and 0.75 bar soil moisture tension at 10 cm depth and drip irrigation. As an average of six crops, for equal amounts of water used drip irrigation gave 60 g/ha or 31% higher yield than irrigation at 0.25 bar soil moisture tension. Irrigation at 0.50 and 0.75 bar tension yielded significantly lower than these treatments. Wetter soil moisture regimes lowered the maximum soil temperature at 10 cm depth by 1 to 3.5°C thereby bringing it closer to the optimum required by the crop. Effect of soil moisture on soil temperature and soil strength was isolated using organic mulches. Soil temperature appeared to be a critical factor in improving yield and quality of potatoes. Drip irrigation promises a more suitable soil moisture and soil temperature regime for potato cultivation in the subtropics.

141. Stevenson, D.S. *Principles of Trickle Irrigation Design.* Canadian Department of Agriculture, Research Station, Summerland, B.C. August 1973.

Article contains advantages and disadvantages of trickle, relationship between distance that water will spread before it begins to pass to subsoil below the root zone in its downward movement, guide to maximum areas that can be irrigated with one emitter, and discusses the strip method and the individual tree method for field layouts.

142. Stevenson, D.S. *Guide to Design and Operation of Trickle Irrigation Systems.* Canadian Department of Agriculture, Research Station, Summerland, B.C. August 1973.

Flow characteristics of black polyethylene greenhouse leader tubing for 1 to 12 foot lengths at pressures of 0.5 to 30 psi are presented. Flow rates, field layout, and overall systems design are discussed.

143. Stevenson, D.S., and Tait, R.S. *Edaphic Micro-Tubular Continuous Flow Irrigation in Canada.* Proceedings of the Second International Drip Irrigation Congress, pp. 86-90. July 1974.

A soil's ability to transfer water horizontally relative to vertical drainage is its most important characteristic in trickle irrigation. Water applied to a soil at a single point will move laterally and vertically. The shape of the resulting half sphere will depend upon the ratio of saturated conductivity to unsaturated conductivity of any particular soil. The limit to horizontal movement before drainage becomes excessive determines that area that we can expect to irrigate with one dripper. Rooting depth of the crop imposes a limit to the area over which water will spread before an excess of it becomes drainage. Evapotranspiration (ET) over the area so defined thus determines the continuous flow from the dripper. Areas and ET are easily equated to provide dripper flows in g.p.h. The areas provide the dripper spacing for uniform irrigation. Micro-tubing of varying sizes and lengths as emitters provides flow control at the emitters for both level and sloping land. Seasonal changes in irrigation requirements (ET) are satisfied by alterations in line pressures as needed.

144. Streutker, A. *Moisture Profiles and Salinization of Soils Under Drip Irrigation in the Republic of South Africa.* Proceedings of the Second International Drip Irrigations Congress, pp. 258-263. July 1974.

Soil moisture profiles, salinization of soils, water use, and production of cotton, potatoes and tomatoes are measured on experimental plots on four soils, from sand to clay, with three different dripper spacings and three different drip intensities. Simultaneously, soil moisture profiles and salinization are measured on different soils under citrus-trees, peach-trees and vineyards with commercial drip irrigation systems under different climates.

145. Sutherland, R.S. *Irrigation in Papayas.* Proceedings of the Subsurface and Drip Irrigation Seminar, University of Hawaii, Miscellaneous Publication No. 102, pp. 34-36. January 1973.

Article is a recap of the research, thought, and experience Alexander and Baldwin, Inc. encountered in a 20-acre papaya planting.

146. Suyemoto, S. *Drip Irrigation of Watermelon.* Proceedings of the Subsurface and Drip Irrigation Seminar, University of Hawaii, Miscellaneous Publication No. 102, pp. 37-38. January 1973.

The use of drip irrigation on melons grafted to wilt - and gummy-stem-resistant gourd rootstock is discussed.

147. Tahnoon, S., and Aljibury, F.K. *Afforestation with Saline Water in Abu Dhabi.* Proceedings of the Second International Drip Irrigation Congress, pp. 370-371. July 1974.

The government of the country of Abu Dhabi is trying to make the desert bloom under adverse soil, wind, and water conditions.

148. Taylor, B.K., and Goubran, F.G. *Effects of Localized Phosphate Treatments and Solution pH on the Growth and Function of Apple Roots.* Proceedings of the Second International Drip Irrigation Congress, pp. 395-399. July 1974.

Following the introduction of trickle irrigation to orchards, interest has risen in the possibility of feeding nutrients into such systems on a regular basis. Use of phosphatic fertilizer in this way, however, could pose a problem in that a highly localized source of P would be available to only a small portion of the root system of the tree. Movement of P away from the trickle outlet would be restricted in most orchard soils by fixation processes. The influence of localized applications of phosphate on the growth and function of apple roots at two pH levels is reported.

149. Thomas, A.W., Kruse, E.G., and Duke, H.R. *Steady Infiltration From Line Sources Buried in Soil.* Transactions of the American Society of Agricultural Engineers, Vol. 17, No. 1, pp. 125-127. 1974.

Paper presents the results of a study of steady infiltration from a distribution of buried line sources which lie in a horizontal plane and are parallel and equally spaced. The sources simulate subsurface irrigation laterals. An analytical solution is made possible by the use of a quasilinear form of the differential flux equation and an exponential relationship between hydraulic conductivity and capillary potential of the soil modeled. The objective of the paper is to develop the analytical solution and compare the computed distributions of capillary potential for normal field lateral spacings and depths with those computed by more complex methods.

150. Toksoz, S., Kirkham, D., and Baumann, E.R. *Two Dimensional Infiltration and Wetting Fronts.* Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, Vol. 91, No. IR3, Paper 4477, pp. 65-79. 1965.

Various processes of two-dimensional infiltration have been studied under field conditions by simulating, in the field, a part of a water recharge absorption trench by a simple 30-cm wide, open trench, the bottom of which was maintained ponded with a thin layer of water applied at the rate needed.

151. Tscheschke, P., Alfaro, J.F., Keller, J., and Hanks, R.J. *Trickle Irrigation Soil Water Potential As Influenced by Management of Highly Saline Water.* Soil Science, Vol. 117, No. 4, pp. 226-231. 1974.

Although trickle irrigation offers the possibility of obtaining comparatively good yields when nontoxic highly saline water is used for irrigation, the subsequent accumulation of salts in the root zone is a potential hazard that should not be disregarded. The objective of this investigation was to determine experimentally the soil water potential and salt patterns in uniform soil profiles as a result of four different water management treatments. Under these treatments cherry tomato plants were irrigated (a) daily with a volume of water equal to that used by the plant on the previous day, (b) every other day with volumes of water equal, (c) below, and (d) above the water evapotranspired. In general, the soil water potential decreased in the soil profile, as a result of salt accumulation, with increased distance from the trickle source. In the profiles where the wetting fronts reached the mid-region between the emitters much lower soil water potentials were measured near the soil surface. 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 whenever highly saline water is used with trickle irrigation. Higher soil water potentials and higher yields resulted from irrigating with volumes above the evapotranspiration.

152. Uys, W.J. *Some Results of a Field Survey of Drip Irrigation Systems in the Republic of South Africa.* Proceedings of the Second International Drip Irrigation Congress, pp. 65-70. July 1974.

An extensive survey was conducted in the Republic of South Africa on existing drip irrigation systems to evaluate drip irrigation systems under a variety of climatic, soil, crop and management conditions. The purpose of the survey is to evaluate drip irrigation systems under practical farming conditions and to identify specific problems of design, operation, and management from which future extension and research programs can be formulated.

153. Uzrad, M., and Goldberg, D. *Disinfection of Soil Strips Through the Drip Irrigation System.* Proceedings of the Second International Drip Irrigation Congress, pp. 137-141. July 1974.

Seasonal crops (vegetables) are often grown on a limited area in the Arava agricultural plots thus causing contamination. Manure of unknown origin increases the rate of contamination. After several seasons of cultivation, there is a marked decrease in the level of the agricultural production. It is customary to disinfect soils by means of methyl bromide. Row crops in the Arava desert are irrigated by the drip system thus the cultivation, fertilization and irrigation is restricted to the cultivated strip. An experiment was conducted to apply the disinfectant only to the cultivated strip through the Drip System. Hot gaseous methyl bromide was applied thorugh the drip laterals and through the drippers which were covered by plastic mulch. The treated areas yielded crops three times higher than in the control plot.

154. Vaziri, C.M. *Design and Layout of a Drip Irrigation System.* Proceedings of the Subsurface and Drip Irrigation Seminar, University of Hawaii, Miscellaneous Publication No. 102, pp. 8-15. January 1973.

Recent development in plastic tubing has enabled irrigation engineers to design effective and economic drip irrigation systems. Soil type, topography, daily evapotranspiration rate, type of crop to be grown, water source, and land area are needed information for drip system design.

155. Vaziri, C.M. *Hydraulics of Single-Chamber vs. Dual-Chamber Tubing.* Proceedings of the Second International Drip Irrigation Congress, pp. 293-298. July 1974.

The basic hydraulic relationship of pressure, orifice diameter, coefficient of discharge, and the friction loss along a tube is a necessity before one can design an adequate drip or subsurface irrigation system. There are several types of tubing and emitters available. But the most unique difference hydraulically is the single chamber tubing versus a dual chamber tubing. The single chamber tube is found to provide an acceptable range of orifice flow uniformity from the head of tubing to the end for approximately 300' of length. Beyond this reach the friction loss in the 1/2" polyethylene tubing is excessive and causes a reduction in the orifice flow rate. The flow rate through each plastic orifice is proportional to the square root of the pressure inside the tubing at the orifice point. The other type of tubing that has been experimented with is a dual chamber tubing. One chamber is for the conveyance. This in turn is connected to the outside chamber (the distribution tube) and water is emitted to the outside through desired orifice spacing, depending on soil types and plantings. Equations are developed to describe the flow pattern for dual chamber tubing and the relationship between the inner and outer chamber. The effect of orifice diameters and orifice spacing on the outer chamber pressure is discussed.

156. Warrick, A.W. *Time-Dependent Linearized Infiltration. I. Point Sources.* Soil Science Society of America Proceedings, Vol. 38, No. 3, pp. 383-386. 1974.

Water flow from a point source is analyzed using a linearized form of the moisture flow equation. Time-dependence is assumed with the results simplified to those of previous investigators for steady-state conditions. Discrete time-distributed inputs such as might occur for trickle or high frequency irrigation is amenable to the solution. Numerical simulations include (i) the advance of a wetting front during infiltration (ii) moisture variation resulting from a cyclic input as during irrigation, and (iii) the matric flux potential field for a two-source problem.

157. Warrick, A.W. *Solution to the One-Dimensional Linear Moisture Flow Equation with Water Extraction.* Soil Science Society of America Proceedings, Vol. 38, No. 4, pp. 573-576. 1974.

The one-dimensional, steady-state moisture flow equation is solved for arbitrary plant water withdrawal functions using the matric flux potential of earlier investigators to obtain a linearized form. A semi-infinite flow medium and a finite-depth medium overlying a shallow water table are considered with the surface boundary condition taken as a flux. Tables are presented giving the matric flux potential (from which the pressure head is easily determined) for several withdrawal functions. Numerical examples show the effects of different surface fluxes and rooting depths on the matric flux potential and pressure-head profiles. The results are particularly relevant for high-frequency irrigation.

158. Warrick, A.W., and Lomen, D.O. *Linearized Moisture Flow Solutions for Point, Line, and Strip Sources.* Proceedings of the Second International Drip Irrigation Congress, pp. 228-233. July 1974.

Solutions and numerical results are given for the time-dependent, linearized moisture flow equation for point, line and strip sources. The linear form is attained by assuming an unsaturated hydraulic conductivity of the form $K = k_o \exp(\alpha h)$ with K_o and α constants and with h the pressure head. In addition, the derivative of K with respect to the volumetric water content is taken as a constant. Numerical results include (1) spatial distribution of the matric flux potential for 6 times including a comparison of two flow rates for a point source; (2) pressure head distribution near a single point source under cyclic conditions; (3) pressure head distribution for 2 point sources under cyclic conditions and (4) moisture distribution patterns near line and strip sources. The major advantage of using the linearized forms is that solutions for simplified geometries may be superimposed both in time and space to simulate complex geometries and inputs of water. The major disadvantage of the nonlinear nature of the soil-hydraulic functions is lost. For cyclic moisture regimes at a high frequency, it is assumed the water content fluctuation of any point will be relatively small and the linearizing assumptions are realistic.

159. Whitney, L.F., and Lo, K.M. *Plastic Orifice Inserts for Subsurface Irrigation.* Transactions of the American Society of Agricultural Engineers, Vol. 12, No. 5, pp. 602-604. 1969.

Designs based on in-wall orifice formation in plastic pipe were found to be completely unreliable with nonuniform output. The rebound of the plastic was unpredictable, with erratic and unstable orifice formation. Labyrinthian protection over drilled orifices provided a more uniform flow rate. The nozzle study culminated with a plastic-insert design which is described.

160. Whitney, L.F., Muta, K., and Pira, E.S. *Effect of Soil Particles on Movement of Water on Subsurface Irrigation.* Transactions of the American Society of Agricultural Engineers, Vol. 12, No. 1, pp. 98-99. 1969.

This research relates to the reaction of water movement at the interface between the different textured soils (loam topsoil and sand subsoil) when water from a pressurized source reaches this interface. While it has long been known that water changes its movement pattern at the texture boundary, the sufficiency of this barrier as an arrester of the downward movement of water is being investigated.

161. Wilke, O.C. *Mobile Drip Irrigation Systems.* Proceedings of the Second International Drip Irrigation Congress, pp. 188-192. July 1974.

A tractor-mounted device for moving drip irrigation laterals is described. Time periods required to load, move and unload laterals are presented. Several drip irrigation trail lines were attached to a pivot sprinkler system. The design and performance of the system are discussed.

162. Wilke, O.C. and Wendt, C.W. *Performance of a Twin-Wall Trickle Irrigation Hose.* American Society of Agricultural Engineers, Paper No. 71-204. 1971.

One trickle irrigation hose consists of two nearly concentric perforated polyethylene hoses. In this report, uniformity of flow from spaced groups of orifices is related to the hose inlet pressure and length. Results of field tests are reported.

163. Willardson, L.S. *Seed Germination Response to Subsurface Irrigation Depth.* Proceedings of the Second International Drip Irrigation Congress, pp. 178-182. July 1974.

A line source subsurface irrigation system was installed at 0, 2.54, 5.08, 10.16, and 20.32 cm depths in a sandy silt soil. The E.C. of the soil varied between 10.4 and 16.2 mmhos per cm. Cotton and alfalfa were used to determine the effect of depth of placement of the seeds and water source on germination.

164. Willardson, L.S., Bohn, G.W., and Huber, M.J. *Cantaloupe Response to Drip Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 474-479. July 1974.

Changes in rooting pattern may change nutrition and plant response, and thus alter desirable characteristics of plants. Five experiments conducted included nine cantaloupe cultivars grown on silty clay loam with drip and furrow irrigation systems. The different irrigation management practices followed have resulted in variable plant responses.

165. Willardson, L.S., Hageman, R., and Marsh, A.W. *Control of Water by Drip Irrigation for Alfalfa Seed Production.* Proceedings of the Second International Drip Irrigation Congress, pp. 172-177. July 1974.

Drip irrigation controlled soil water tension treatments in an alfalfa seed production experiment resulted in a 4-fold yield difference between the best and poorest treatments. The experiment had 6 replications of 4 treatments and has been conducted for two years. Yield of forage as well as seed yields were determined.

166. Willardson, L.S., and Oster, J.D. *Salinity Sensor Control of Drip Irrigation Water Application.* Proceedings of the Second International Drip Irrigation Congress, pp. 335-340. July 1974.

In-situ salinity sensors were used to control water application by drip irrigation to maintain a constant soil salinity. Milo was grown on small field plots instrumented with salinity sensors to evaluate the effect of depth of placement and initial soil salinity on plant growth and water control. Water application was fully controlled by the sensors. Response time was short enough to encourage practical use.

167. Willens, A.F., and Willens, G.A. *An Investigation Into the Potential Uses of Trickle Irrigation for Desert Reclamation and Fodder Production in the Emirate of Abu Dhabi.* Proceedings of the Second International Drip Irrigation Congress, pp. 388-393. July 1974.

An initial investigation into the possible uses of trickle irrigation to establish a range of plant species which could be potentially useful as fodder is described. The use of trickle irrigation for fodder tree production shows considerable potential and appears economically viable within the present social context of Abu Dhabi.

168. Willoughby, P., and Cockroft, B. *Changes in Root Patterns of Peach Trees Under Trickle Irrigation.* Proceedings of the Second International Drip Irrigation Congress, pp. 439-442. July 1974.

With fully mature peach trees, which before the installation of a trickle system had a uniformly distributed root system through the whole orchard area, a change to trickle produced a remarkable adaption by the tree. A whole new root system was developed in a few months, and the trees continued to produce heavy crops of fruit.

169. Wolff, P. *Use of Drip Irrigation in Germany.* Proceedings of the Second International Drip Irrigation Congress, pp. 71-76. July 1974.

Irrigation methods similar to drip irrigation have been used in Germany for many years, and more horticulturalists are changing from overhead irrigation to drip irrigation. The reasons for changing irrigation methods were investigated by the author and his coworkers. It was found that the horticulturalists are changing methods because of increasing labor costs and an increasing demand for high quality products.

170. Wu, I.P. *Drip Irrigation on Hawaiian Vegetables.* Proceedings of the Subsurface and Drip Irrigation Seminar, University of Hawaii, Miscellaneous Publication No. 102, pp. 16-21. January 1973.

Irrigation experiments were conducted to determine water requirements for different vegetables, and theoretical studies on energy relations were made to develop design criteria for drip irrigation systems for vegetable farmers.

171. Wu, I.P., and Fangmeier, D.D. *Hydraulic Design of Twin-Chamber Trickle Irrigation Laterals.* Agricultural Experiment Station, Technical Bulletin No. 216, University of Arizona, Tucson, Arizona. 1974.

A computer program was developed to calculate pressure and discharge distribution along a twin-chamber trickle irrigation lateral line. The program uses the Darcy-Weisback equation for hydraulic loss in the main or supply chamber. The friction coefficient is obtained using separate equations for laminar, transitional, and turbulent flow. The validity of the computer program was checked by comparing results with data from laboratory and field experiments. Design charts were developed for various orifice spacings to determine maximum lateral length or input pressure and the total discharge. The same technique can also be used to develop design charts for single chamber irrigation tubes.

172. Wu, I.P., and Gitlin, H.M. *Trickle Irrigation: A Preliminary Survey and a List of Manufacturers.* Cooperative Extension Service, University of Hawaii, No. 10. January 1972.

A trickle irrigation system is designed to deliver irrigation water directly near the root system of plants. The system applies water slowly under pressure to keep the soil moisture within the desired range for plant growth.

173. Wu, I.P., and Gitlin, H.M. *Procedures for Designing Drip Irrigation Systems.* Cooperative Extension Service, University of Hawaii, No. 11. October 1972.

The design factors for drip irrigation system design are briefly discussed and design examples are presented. A table is provided for determining friction losses in plastic (schedule 40) pipe.

174. Wu, I.P., and Gitlin, H.M. *Hydraulics and Uniformity for Drip Irrigation.* Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, Vol. 99, No. IR2, pp. 157-168. June 1973.

This study has shown that the pressure distribution along the lateral can be estimated by the line slope and energy drop calculated by using average discharges of three or four sections. This will cause an error of less than 2% in comparison with a pressure gradient line calculated by using all sections between emitters. The calculation is based on a uniform flow from all emitters and a constant emitter spacing. If the pressure distribution is determined along a lateral line for constant flow for each emitter, then uniform irrigation can be achieved by using different sizes of emitters, different lengths, or different sizes of microtubes and spacing between emitters. The study encompasses the basic energy relations of a drip irrigation system and several ways to achieve better uniformity of output for a drip irrigation system.

175. Wu, I.P., and Gitlin, H.M. *Drip Irrigation System Design: Friction Drop for Plastic Microtubes.* Cooperative Extension Service, University of Hawaii, No. 12. March 1974.

The use of microtubes in drip irrigation systems is discussed, and charts are presented for determining the friction loss in microtubes.

176. Wu, I.P., and Gitlin, H.M. *Design Charts: Lateral and Submain Design for a Drip Irrigation System.* Cooperative Extension Service, University of Hawaii, No. 13. April 1974.

Design charts for both lateral and submain lines were developed for different tubing sizes and for up and down slopes based on the hydraulics of drip irrigation lines.

177. Wu, I.P., and Gitlin, H.M. *Design of Drip Irrigation Lines.* Hawaii Agricultural Experiment Station, Technical Bulletin No. 96, University of Hawaii. June 1974.

The friction drop in a drip irrigation line can be determined by considering turbulent flow in a smooth pipe. The pattern of friction drop along the length of a drip line is determined and expressed as a dimensionless curve. This curve combined with the slope effect will show the pressure distribution along the line. Design charts are introduced for determining pressure and length of drip irrigation lines.

178. Wu, I.P., and Gitlin, H.M. *Design Charts for Drip Irrigation Systems.* Proceedings of the Second International Drip Irrigation Congress, pp. 305-310. July 1974.

A simple design procedure has been developed for drip irrigation systems installed on either uniform or nonuniform slopes. The charts presented can be used to design a system with an allowable discharge (emitter) variation up to 20%. A dimensionless energy gradient curve has been developed theoretically for drip irrigation lines, submain and lateral, and was checked by laboratory and field experiments. It was found that a typical dimensionless energy gradient curve which was developed by using turbulent flow in smooth pipe can be used for flow conditions having 20% discharge (emitter) variation and percentage of laminar flow up to 30%. The dimensionless energy gradient curve combined with different slope conditons will show the pressure variation along the drip irrigation line. Design charts have been developed for both single tubing and twin-chamber drip irrigation systems. Examples are presented showing the design procedure.

179. Wu, I.P., and Gitlin, H.M. *Drip Irrigation Design Based on Uniformity.* Transactions of the American Society of Agricultural Engineers, Vol. 17, No. 3. 1974.

The paper presents a general shape of the energy gradient line which can be applied to estimate distribution and variation of emitter discharge along the lateral. A design chart is presented for determining an acceptable combination of lateral lengths and inlet pressure of a drip irrigation system. The chart helps in selecting a drip irrigation line based on a desirable or acceptable uniformity coefficient. The designer can try different combinations of pressure and length in order to obtain a design which is acceptable.

180. Yagev, E., and Choresh, Y. *Drip Irrigation in Citrus Orchards.* Proceedings of the Second International Drip Irrigation Congress, pp. 456-461. July 1974.

In a Valencia orange grove grafted onto sour orange root stock, drip irrigation treatments of one and two laterals per row of trees at semi-weekly and bi-weekly intervals were compared to the standard treatment of sprinkler irrigation. The water application to all treatments was based on identical daily rates. The factors checked were salt accumulation and moisture distribution pattern in the soil profile, root development, mineral content of leaves, weight of yield and number of fruit per tree, and fruit quality. There was no difference in yield and fruit quality between the treatments checked. The average salt accumulation in the soil was less with the drip irrigation treatments than with the sprinkler irrigation. The soil moisture tension below the drip lateral was low all the time and there is reason to believe

that there is a loss of water below the root zone. There was no significant difference in root development between all the treatments.

181. Zentmyer, G.A., Guillement, F.B., and Johnson, E.L.V. *The Relation Between Drip Irrigation, Phytophthora Root Rot of Avocado, and Fungicides.* Proceedings of the Second International Drip Irrigation Congress, pp. 512-514. July 1974.

Studies have been initiated to determine the effect of drip irrigation on development, spread and control of Phytophthora root rot of avocado caused by Phytophthora cinnamomi. In one test in naturally infested soil, development of Phytophthora root rot of avocado seedlings was considerably slower under drip than under sprinkler irrigation. There were also indications of less rapid spread of the fungus from infested into noninfested soil under the drip, as compared with the sprinkler regime. At the end of the first year of the experiment, 6 of 12 seedlings were still healthy in soil infested with P. cinnomomi when irrigated with a drip system, compared with 2 healthy seedlings of 12 irrigated with spitters. A number of soil fungicides have been tested in the greenhouse for possible use in drip systems, by applying frequent applications (every other day or every fourth day) to avocado seedlings growing in soil infested with Phytophthora cinnamomi. The best control of the disease has been obtained with ethazol (5-ethoxy-3-trichloremethyl-1, 2, 4-thiadiazole) chemicals for incorporation in drip systems is still in the early stages. One field plot has been established with Terrazole applied in a drip system to 10-year old avocado trees infected with Phytophthora root rot, and also to young trees replanted in infested soil.

182. Zetesche, J.B., and Newman, J.S. *The Design of Subirrigation Laterals with Uniformly Spaced Orifices.* American Society of Agricultural Engineers, Paper No. 68-759. 1968.

Subirrigation with perforated small diameter plastic pipe offers many irrigation advantages such as reduced labor requirement, increased water use efficiency, and a permanent solid-set system. The hydraulic design of the system is analyzed and a method of design solution given.

APPENDIX

Key Word Index

KEY WORD INDEX

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