IRRIGATION SYSTEM EVALUATION AND IMPROVEMENT

by

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PREFACE

Second Edition

The wide interest in the First Edition of this guide to better irrigation has been encouraging. It has been used by irrigators, managers, technicians and students with varying backgrounds in irrigation. For some, the explanations have been too detailed, and others would like to see more advanced materials presented.

In the interest of wider usage of the evaluation techniques and suggestions for better irrigation management practices, the first edition prepared by John L. Merriam, has been expanded by including basin irrigation, simplified techniques of all methods, more explanation of standard procedures and more advanced details in the Appendices.

The section of sprinklers has been enlarged to include several variations. The enhancement of the booklet by some of the new sprinkler and trickle information has been made possible by having Dr. Jack Keller, Professor at Utah State University, as co-author. Dr. Keller is widely experienced in the research and application of these two methods.

Dr. Jose F. Alfaro from Utah State University has also assisted in the general revisions and has undertaken the challenge of re-writing the text using the Spanish language and metric units.

The authors wish to express their appreciation to Safa Noori Hamad for his tremendous effort in supervising the revisions and typing of the Second Edition; and to the Secretaries for their patient typing.

To help eliminate confusion with other more general definitions, some definitions from the First Edition have been re-named. Application Efficiency has been re-named Actual Application Efficiency; Irrigation System Efficiency is now called Potential irrigation system Efficiency; and Distribution Efficiency has been changed to Distribution Uniformity.

ABSTRACT

This second edition of the manual contains detailed procedures for the field evaluation of sprinkler, surface, and trickle irrigation performance and management practices. It contains details such as: a list of equipment needed; step by step instructions for carrying out the field work; sample forms for recording and organizaing the field data; and sample studies demonstrating the entire process. It also includes an analysis and recommendations for the actual care studies used.

The introduction deals with the general uniformity, efficiency, and management concepts employed in the evaluation of each system. The sprinkler section covers both simple and full evaluations of regular fixed grid sprinkler systems as will be under tree orchard, center pivot and traveler sprinkler systems. There is a brief section dealing with trickle (or drip) irrigation and a section on basic irrigation. Both the furrow and border irrigation sections contain a simple (short cut) evaluation procedure as well as complete full evaluations.

Key Words: Irrigation, Efficiency, Uniformity, Sprinklers, Trickle, Basin, Border, Furrow, Soil, Moisture, Evaluation.

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CHAPTER I

INTRODUCTION

Irrigation systems may or may not be well designed and properly used. The system evaluation techniques which follow are designed for evaluating the *Actual* operation and management conditions which exist and determining the *Potential* for a more economical and efficient operation. This type of study is necessary to provide direction to management for either continuing existing practices or making essential improvements.

Improved on-farm water management may result in conservation of water, soil and labor as well as increases in crop yields. An evaluation can show the effectiveness of existing irrigation practices. A study of the evaluation will indicate what improvements can be made and provide management with a basis for selecting potential economical and practical modifications.

Most modifications involve simple changes in management practices. Evaluations frequently indicate the need for soil moisture deficiency checks and better maintenance practices. Indicated changes often save labor as well as water. Sometimes capital investments to provide mechanization or automation are in order.

Sprinkler systems may be greatly improved by simple changes such as: altering operation pressures, nozzle sizes, riser heights, and durations of water application; operating at different pressures at alternate irrigations; using alternate set sequencing; obtaining larger size lateral pipes; tipping risers along the edge of the field, etc.

For moving-water surface irrigation methods (furrows and border-strips) the following simple changes may greatly improve performance: larger, smaller or cut-back streams; irrigating at a different soil moisture deficiencies; different furrow spacing or shapes; revision of strip width or field length; supplemental pipe lines often utilizing portable gated pipe; runoff water return-flow systems; etc. Capital investments such as land grading for a smoother surface or more uniform soil, constructing reservoirs, increasing water delivery capacity, semi-automation, etc., are often profitable and also improve water use efficiency and save labor.

Basin irrigation systems may be greatly improved by changing the location of a dike to conform to soil changes, more careful land grading to achieve a level surface, or changing the basin area to better match available stream size.

Trickle systems may requir^ a different length of application or irrigation frequency. Additional filtration may be needed. Some systems may need a higher density of tricklers.

Labor and water saving are usually closely correlated with a water supply which is flexible in *frequency*, *rate* and *duration*. Efficient water use is only achieved if water can be: 1. supplied close to the day it is needed to match the crop and weather, *frequency*; 2. furnished at a rate that can be changed to match different field sizes, cut-back streams, varying intake rates and large enough to keep the irrigator busy, *rate*; 3. turned off when the soil moisture deficiency and leaching requirements are satisfied, since all flow after this time is wasted, *duration*.

A principle cause of low efficiencies is over-irrigation. With furrows and border-strips, excess water is largely runoff which may be recovered with a return-flow system. With basins, sprinklers and trickle systems, excess water infilters and contributes to the ground water and may be recovered by wells if it goes deep, or may cause a drainage problem if restricted at a shallow depth.

Basic Terminology

There are several concepts and definitions that are basic to all irrigation methods and evaluations. Some of the most important ones are presented below, and others are included in the Glossary along with some additional explanation.

Evaluation consists of an analysis based on field measurements taken under the conditions and practices normally employed, plus on-site studies of potential modifications such as presures other than the one being used, larger and smaller furrow streams, change of duration, etc. Measurements needed for the analysis include soil moisture deficiency, inflow rate, application and infiltration uniformity, application duration, advance rate, soil conditions, infiltration rates, irrigation adequacy, etc.

Soil moisture deficiency, smd, is expressed as a depth indicating the dryness of the root zone at a particular time. This depth is numerically identical to the depth of water to be replaced by irrigation under normal management. Therefore, the idea of moisture deficiency in the root zone is preferable to the commonly used concept of depth of water in the soil.

How dry the soil should be before irrigation is needed, is related to the soil moisture tension at that smd and how well the crop will grow at that stress. Some crops produce better when kept moist by frequent irrigations, however, diseases and pest problems may also be increased. Other crops may produce more economically when allowed to become quite dry between infrequent irrigations which also reduces irrigation labor costs.

Management Allowed Deficiency, MAD, is expressed as the allowed soil moisture deficiency used to schedule irrigations so that net crop returns are maximized. The MAD is first related to soil moisture and crop stress and is expressed as the percent of the total available soil moisture that can be extracted from the root zone between irrigations to produce the best economic balance between crop returns and irrigation costs. Secondly, it is expressed as the corresponding depth deficient for a given root depth and soil having a specific available moisture content. This deficiency is related to a soil moisture stress, at which an irrigation should be applied.

The evaluation of furrow and border-strip irrigation systems should be made when the MAD is reached, since intake rate, water movement and duration of irrigation are greatly affected by soil moisture conditions. Because of the appreciable effect of the MAD on these factors, small variations in the MAD become one of the improvement management tools for obtaining desired operation improvements for surface systems, especially border-strip. This is true because of the rapid decrease in infiltration rate as the duration of application continues.

Irrigation system operation depends as much on the irrigator as on the quality of the system. The system may be properly used, or abused. To determine the best use involves making a thorough evaluation of the system, or having appreciable experience and using short cut evaluation procedures. However, the following questions must always be considered to obtain the best possible efficiency from any given system.

1. Is it dry enough to start irrigating?
2. Is it wet enough to stop irrigating?

The soil moisture deficiency must be known to answer the first question. It should be the same as the MAD. The simplest method for determining smd is by field observation of the color and plasticity of the soil. This only requires comparing soil samples taken from the root zone (preferably the full depth) with the chart given in Appendix A. Other methods for evaluating smd include the use of tensiometers for low MAD values (high moisture situations) and absorption blocks or similar equipments for high MAD values. Weighing and drying samples is quite precise, but slow and cumbersome.

Water budgets using climatic based methods, such as evaporation and other methods for estimating the water consumed by the plants, Potential Evapo-transpiration, are also satisfactory. The estimated smd from the water budgets should occasionally be checked by field observations in the lower part of the root zone to see that an accumulative smd is not occurring. Unfortunately, such checks will not indicate over-irrigation.

The second question of when to stop irrigating is of equal importance, because all water applied after satisfying the smd and leaching requirements is completely wasted from the root zone. A probe, typically a 5/16 in. or 3/8 in. steel rod about four feet long with a slightly bulbous (not pointed) tip and a tee handle, can be used in most soils to quickly check the penetration of irrigation applications at numerous points throughout the field. It will easily penetrate to a moderate depth of about three feet through the nearly saturated soil being irrigated, but encounters considerable resistance as it meets the drier soil or plow pans below. The proper depth of probe penetration will be appreciably less than the desired final depth of water penetration, since water will drain deeper after irrigation. This requires that the probe depth be correlated later with an adequate irrigation.

A number of soil moisture sensing devices can be used to give an indication of when to stop irrigating, but none are easier to understand and construct than the simple probe. Some devices may be connected to turn the system on and off automatically. However, they must be correlated with values at the sensing point to values representative of the entire field under control.

With sprinkler and trickle irrigation systems the rate or volume of application is usually known. When the uniformity of application is reasonable, the depth of application can easily be controlled by the duration of the irrigation. However, field checks must be made as for all methods to make certain the desired depth of application has been accomplished and an excess is not being applied.

Soils and crop information are fundamental to all irrigation work. The optimum MAD is interdependent on the specific soil, crop, root zone depth, climate and irrigation system. It should be established as it affects the depth, duration and frequency of irrigation.

The available moisture, intake rate, method adaptability and choice of crop are all related to soil texture; whereas root zone depth, intake rate, lateral wetting, perched water tables and adaptability to land grading are mostly affected by soil profile and structure. The uniformity of a soil in a field is also important as it affects the uniformity of infiltration and choice of irrigation methods. It must be thoroughly investigated during field surveys. For all methods, the frequency and depth of irrigation within a field should be related to the soil with the lowest MAD.

Sprinkler or trickle irrigation is recommended for fields with variable soils and topography, since the depth of application is independent of surface variations. The application rate should be below the basic infiltration rate of the slowest intake areas.

Reasonable soil uniformity is important for efficient furrow or border-strip irrigation. The possibility of improving the soil uniformity within each field should not be overlooked during the land grading process. In basins the intake rate uniformity is of even greater importance. However, a high level uniformity can often be obtained by making the basin boundaries conform to soil boundaries. The ridges can be farmed over or termporarily removed as needed and the shape or sizes of basins varied as required.

Irrigation methods can be classified into five basic techniques, each with several variations. Each technique and variation has characteristics which are more or less desirable for different locations and crops. The basic component and concept of each of the five techniques are:

1. Basin: A level area of any size or shape bounded by borders or ridges which retains ponded water until it infiltrates. Water loss is by deep penetration.

2. Border-strip: A sloping area usually rectangular in shape, bounded by borders or ridges to guide a moving sheet of water as it flows down the bordered strip. The supply of water is typically cut off when the advancing sheet is eight to nine-tenths of the way down the strip. Water loss is by deep penetration and runoff.

3. Furrow or corrugation: A small sloping channel cut out or pressed into the soil surface. It is usually "desirable" that the irriga-

tion stream reaches the end of the channel in about one-fourth of the time of irrigation. The stream is not shut off until the lower end of the channel is adequately irrigated. The wetted front moves laterally as well as vertically from the channel, so that infiltration is a slow process. Water loss is by deep penetration and runoff.

4. Sprinkler: A device for spraying the water over the surface. The water is discharged from a sprinkler into the air and should infiltrate the soil where it falls and not saturate the soil surface in the process. With closely spaced sprinklers, a good uniformity of application can be achieved even in high winds. Water loss is by evaporation, wind drift and deep penetration.

5. Trickler: A device for discharging water at very low rates (less than 3 gallons per hour) through small holes from tubing placed on/or slightly below the soil surface. Water moves through the soil sideways as well as downward away from the point of application to form a bulb of wet soil. Typically, only a portion of the soil mass is kept quite moist by very frequent or continuous application. Water loss is by deep penetration.

Table I-1 presents the major physical characteristics affecting the adaptability of each of the five basic irrigation techniques. The Potential irrigation system Efficiency, PE, of a well designed and properly used system, employing each technique where adaptable, is also presented. Automation or mechanization of most systems is possible to reduce labor. Such items as salinity, micro climate control, etc., were not considered and personal desires and costs have been omitted.

Efficiency terms used in irrigation have been variously defined. To avoid confusion, the three primary terms which will be used in the field evaluation procedures are defined below. They are also included in the Glossary, along with some other useful definitions. These terms are given new descriptive names relative to the First Edition and other publications to help avoid confusion with other terms and definitions.

High efficiency values may or may not be economical. However, the efficiencies must be evaluated before economic management decisions can be made. Efficiencies computed from ordinary field data are only accurate to about the nearest 5%. Therefore, variations in efficiency values of less that 5% may not be significant except where comparisons are being made from the same data.

Table I-1. Major physical requirements and potential efficiencies of the basic irrigation techniques.

Method	Soil Uniformity	Infiltration Rate	Ground Slope	Stream Size	Labor Requirement	Potential Irrigation Efficiency
Basin	uniform within each basin	any	level, or graded to level	large relative to basin size	intensive at infrequent intervals	75% to 85%
Border-strip	uniform within each strip	any but extremes	mild and smooth	large relative to strip area	same as above	70% to 80%*
Furrow or Corrugation	uniform for full length	but very rapid	mild, or "contour"	medium	intensive to intermittant at infrequent intervals	70% to 80%*
Sprinkler	may be intermixed soils	any but very slow	any farmable slope	small, continuous	few hours daily	75% to 85%
Trickle	may be intermixed soils	any	any farmable slope	small, continuous	very low	80% to 90%

*Values of 90% can be attained if runoff water is re-used.

1. Distribution Uniformity, DU, gives an indication of the uniformity of infiltration throughout the field.

$$DU = \frac{\text{minimum depth infiltered}}{\text{average depth infiltered}} \times 100$$

The DU is useful as an indicator of the magnitude of the distribution problems. A low DU value indicates there will be excessive deep percolation losses and a potential high water table if adequate irrigation water is applied to all areas. If excessive deep percolation is controlled, the area receiving the minimum depth will be badly under-irrigated.

2. Actual application storage Efficiency, AE, obtained in the field gives an indication of how well a system is being used, or if it is being misused.

$$AE = \frac{\text{minimum depth infiltered and stored in the root zone}}{\text{average depth applied}} \times 100$$

Implicit in this equation is a measure of uniformity and the concept that the minimum depth stored satisfies the soil moisture deficiency. It shows that all the area is receiving water for any value greater than zero. Low values of AE generally indicate management and/or system problems associated with over-irrigation. Additional factors must be considered as presented later, when a field is intenionally under-irrigated.

3. Potential irrigation system Efficiency, PE, gives a measure of system performance attainable under reasonably good management when applying a full irrigation.

$$PE = \frac{\text{minimum depth infiltered just equaling smd or MAD}}{\text{average depth applied}} \times 100$$

The PE is a particular and identical value of AE when the desired depth of water has been infiltered. A low value of PE is usually associated with poor system design (unless intentional for economic reasons). The difference between PE and AE is a measure of management problems.

Meaningful comparisons between several systems modifications or methods can only be made by comparing values of PE. They must be made when applying similar MAD depths, and with identical specification of "minimum" depth. Economic comparisons must also include costs and crop production factors.

Minimum depth infiltered as used in the several equations, is defined in three ways: 1. the absolute minimum measured; 2. the average of the lowest 1/4 of the values (proposed by the Soil Conservation Service, USDA); 3. the average of the lowest 1/2 of the values (used in Christiansen's Coefficient of Uniformity). The first one implies that no area receives less than the measured minimum, the second that 1/8 of the area receives less and the third that 1/4 receives less.

For the concept of efficiency to be practical, the area below "minimum" must be small but also greater than zero. the SCS minimum is recommended for normal use in evaluations.

Intentional Under-Irrigation

Most often systems are designed or managed to fill the smd throughout the entire root zone at each irrigation; however, this is not always the objective. Furthermore, sometimes the irrigation interval is extended to reduce the water use rate below peak values. Such practices are utilized to aid other cultural practices, reduce system capacity requirements and/or to obtain maximum yields per unit of water or per unit of capital cost. This intentional under-irrigation may be imposed rather uniformily throughout the field, only in areas receiving minimum infiltration or selectively.

Maximizing water-production efficiency is quite important where the water supply is inadequate and the value of water is measured by productiveness per unit of water. In such cases operating at a high MAD results in extending the irrigation interval. This practice, which is termed *Stress Irrigation* may reduce yields per unit area but produce more total crop per unit of water on an increased area and a greater net return. This practice also allows for better utilization of rainfall. Except for some of the variations mentioned below, intentional under-irrigation puts a premium on having high values of Distribution Uniformity, DU, and Actual application storage Efficiency, AE, to reduce water losses and results in a higher Transpiration Ratio, TR.

With a root zone full of moisture at the beginning of the peak water use growth period, under-irrigation can improve water use efficiency without reducing yields. (This procedure is a variation of *limited irrigation.*) This is only possible, however, if the peak use period is relatively short and followed by a period of lesser use, or by harvest. The moisture stored deep in the root zone from early or off season irrigation and rain water will be consumed during periods of under-irrigation, thereby making more water available for crop production. It involves having an assured deep root zone water supply from rain or early full irrigations on a maximum area, and then not replacing the smd at each irrigation during the peak use period. This reduces deep percolation losses if DU is high but allows a cumulative smd to develop in the bottom portion of the root zone which serves to augment the limited irrigation supply. Frequent checks of the smd are essential to obtain the maximum benefit of this practice and to avoid the danger of running out of deep moisture reserves and stressing a crop at a critical period (such as corn at tasseling). The amount of land irrigated should not exceed that which can be economically irrigated with the limited irrigation water supply plus the deep soil moisture reserve.

Another means of maximizing water use efficiency and reducing system capacity is accomplished by irrigating only part of the area in orchards or vineyeards, with furrows· tricklers or orchard sprinklers. The full soil profile throughout the area should be wet from rain or early season irrigation. During the peak water use period irrigation should be restricted to applying the smd to only a portion of the surface area surrounding each tree. This will reduce surface evaporation and thereby decrease TR. A high or low MAD may be used in the area wetted which will or will not stress the crop slowly as it draws from the un-irrigated areas. In either case this practice will utilize the available water supply very efficiently. The term stress irrigation applies where yields are reduced and limited irrigation where yields are unaffected by such practices. The location of the tree area watered is unimportant, since root systems in a mature orchard are extensive.

Irrigation procedures which tend to excessively stress the crop can be combined with *alternate side irrigation* to reduce the maximum stress. The technique is to irrigate the crop at about 1/2 the normal interval but only irrigate one side each watering alternating to the other side on the following irrigation. This practice is practical for orchards as well as row crops.

Other cultural practices sometimes require modification in irrigation design and management. The pre-harvest irrigation depth could be reduced permitting the limited water to be spread wider and shallower. Thus, the deep soil moisture would be utilized leaving the surface dry shortly before harvest.

Sometimes furrows cannot be constructed close to the tree because of branches or props, or sprinklers are placed only in the tree row to reduce problems with foliar interception. A common practice in young orchards under basin, furrow, sprinkler, or trickle irrigation is to irrigate only the area immediately adjacent to the trees until the roots become more extensive. Even in mature orchards, only a portion of the surface area may be wetted to improve trafficability. In fact, this is one of the prime features of trickle irrigation which is seldom, if ever, designed to wet the total soil area. Under such conditions the reduction in area is compensated by more frequent irrigation in inverse proportion to the area reduced, e.g., half the area, twice the frequency, which is a prime example of *limited irrigation.*

Reduced capital investments are possible by reducing system capacities as discussed above and/or reducing the uniformity of application. With low uniformity systems the smd may not be fully replaced in portions of the field even where there is an adequate water supply. In such cases there is planned acceptance of a reduced yield in the dry portions of the area. Such systems require careful management, knowledgeable design, soil moisture deficiency checks and periodic evaluations to measure the success of the operation. relatively low uniformity and some under-watering of the driest areas is particularly applicable to solid set sprinklers and longer than normally desired or poorly graded surface irrigated fields of low value crops.

This above design procedures anticipate moderate to low values of DU and AE as a trade off for reducing system development costs. Wide sprinkler spacing and low pressures will cost less but cumulative soil moisture deficiencies will occur in the drier spots unless excessively large quantities of water are applied, which could be uneconomical or cause drainage problems. The dry spots will produce less crop, however, profits may be maximized because the reduced capital costs more than offset crop losses.

For furrows and border-strips reduced land grading or longer than normally desired run lengths may be used to decrease capital and labor costs. Only where the cost reductions are adequate to more than compensate for reduced production at the under-irrigated far end of the furrow or strip should such practices be employed.

Trickle irrigation systems are almost always designed to irrigate less than the whole surface area in widely spaced tree crops. This is done in part to reduce capital costs. Great caution should be exercised, however, where systems are designed to irrigate less than 1/3 of the potential root soil volume.

For all of these variations of *stress* or *limited irrigation*, the value of the crop decrease should be more than offset by the savings in capital, labor, water and management required.

High Frequency Irrigation

Portable and permanent solid set (or full coverage) sprinklers, center pivot sprinklers and trickle (or drip) systems are normally managed to apply light frequent irrigations. The reasons for using high frequency irrigation are to: maintain a continuous high soil moisture level for higher yields or better crop quality; reduce run-off problems associated with high application rates as discussed in the section on center pivot sprinklers; and control temperature, humidity and wind erosion.

Under high frequency irrigation the depth of each application is often less than an inch. Unless intentional under-irrigation is being practiced, the soil moisture deficit, smd, would also be less than an inch. It is practically impossible to estimate the smd with enough precision to be of value for determining if it is dry enough to irrigate when such a low Management Allowed Deficiency, MAD, is being used.

Estimates of the crop water use rate give a good basis for scheduling high frequency irrigation. The crop water use estimate can be made from climatic data, taken from evaporation pan measurements, or based on experience. Except where intentional under-irrigation is being used, the ideal system management would exactly replace the water consumed (in the areas receiving the minimum application).

It is not practical to get an exact estimate of the water actually consumed between irrigations. Since over-irrigation is difficult to determine, a good management practice is to slightly under-irrigate. Periodic smd checks can then be made to spot any areas of cumulative soil moisture deficits and the irrigation scheduling can be corrected accordingly.

High frequency irrigation is particularly well suited for use in conjunction with *limited irrigation* where the deep soil moisture is being gradually depleated. The light frequent watering of the top soil plus the gradual moisture withdrawal from the sub-soil can produce optimum production with a limited system capacity. However, where the sub-soil moisture is not sufficient, light frequent irrigation may result in the inefficient use of a limited supply and less frequent deeper irrigations may produce better results.

Under supplemental irrigation in high rainfall areas a good practice is to apply high frequency irrigation while maintaining the smd between 1 and 2 inches. Thus, there is always storage capacity for some rain and plenty of water for the crop.

Uniformity, Efficiency, and Economics

The efficiency of an operation is a measure of how well it is performing compared to some ideal level of performance. The purpose of irrigation is to maximize profit and/or production, not to save water.

Economic (irrigation) efficiency is the ratio of the total production (net or gross profit) attained with the operating irrigation system, compared with the total production expected under ideal conditions. This parameter is in effect a measure of over-all efficiency because it relates the final output to input.

The evaluation procedures which follow generally imply that full irrigation with a high uniformity is the desired ideal. The concept of full irrigations in the areas infiltering the minimum depth of application is useful for standardizing field evaluation procedures. However, it may provide a poor basis for evaluating and managing a system to optimize *economic efficiency*.

As a general guide, the most economic systems for various crops and soils should have the following Distribution Uniformities:

1. High value crops, especially those with shallow roots - DU above 80%.

2. Typical field crops with medium root depths on medium textured soils - DU between 70 and 80%.

3. Deep rooted orchard and forage crops and where there is a substantial quantity of supplemental rainfall - DU between 60 and 70%. (Sometimes DU values as low as 50% may even be the most economical in supplemental rainfall areas with low value crops.)

As mentioned earlier, intentional under irrigation in the areas receiving the minimum depth of application may provide the optimum *economic efficiency*. Rather than replenishing the water in almost all of the area, as is implied by PE, it may be more economical to leave a substantial area under-watered. This would be especially true for deep rooted crops, low value crops and/or in humid areas. If the average depth infiltered in the low half of the pattern is used as the minimum depth one-fourth of the area will be under-watered.

A detailed study, which is beyond the scope of the following evaluation procedures, is needed to optimize economic efficiency. In addition to the field evaluation of the system it would require a thorough knowledge of economic system inputs plus the relationship between crop production and water for the study area.

CHAPTER II
SPRINKLER IRRIGATION

A number of different types of sprinkler systems have been developed. Techniques for evaluating the most widely used of these are presented below. The sprinkler systems discussed include the following:

Fixed grid where the sprinklers are spaced in a grid pattern with sufficient overlap to spread the water fairly uniformly over the entire surface area. Hand move, side roll, end tow, side move with multiple trail lines (or block move), portable full coverage (or solid set) and permanent solid set systems are included in this category. (See Figures II-1 and II-2.)

Orchard where there is little or no overlap between sprinklers which are placed under the tree canopy and spaced to provide a uniform amount of water to each tree.

Water should be fairly uniformly applied to the wetted areas even though some of the area around each tree will receive little or no irrigation water. (See Figure II-3.)

Center pivot where water is sprinkled from a pipe line which is supplied from a stationary pivot point and rotated while watering to irrigate a large circular field. (See Figure II-4.)

Giant traveler where a high capacity sprinkler is fed by a flexible hose and travels while watering. (See Figure II-5.)

The first extensively used sprinkler systems employed the fixed grid concept using rotating sprinklers spaced along portable "hand move" lateral pipe. To reduce labor, the lateral pipelines may be mechanically moved after each set. To make the systems automatic and practically eliminate labor, the systems are laid out with sufficient pipe and sprinklers so the entire field can be irrigated by switching valves on and off without moving any pipe.

The simple and full evaluation techniques which immediately follow are useful for all of the over canopy or open field systems which are irrigated by rotating sprinklers at a fixed position while watering. The sprinklers on all of these systems distribute water in a conical pattern and depend on overlap from several sprinklers to obtain relatively uniform wetting.

A simple evaluation can provide an awareness of the more obvious management problems with a minimum of effort. It can be done quickly with simple equipment; however, insufficient information is provided for designing system changes. In contrast, a full evaluation not only identifies problems but also indicates corrective design alternatives.

Most sprinkler systems are efficiently designed to meet the peak evapo-transpiration requirements which only occur during part of the season. The manager should be aware of the system's capabilities in order to adapt the operation to changing conditions imposed by the crop and weather.

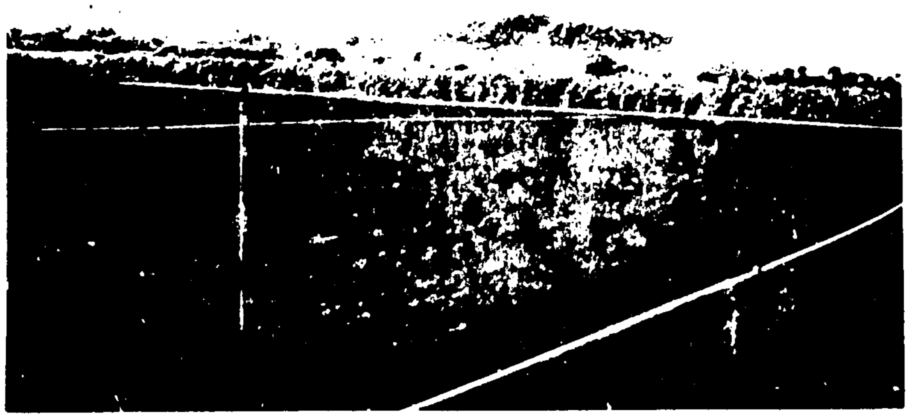


Figure II-1. Hand move psrinkler lateral - for fixed grid pattern.

Figure II-2. Side roll sprinkler lateral for a fixed grid pattern.

Figure II-3. Orchard sprinkler system.

Figure II-4. Center pivot sprinkler system in a sugar beets field.

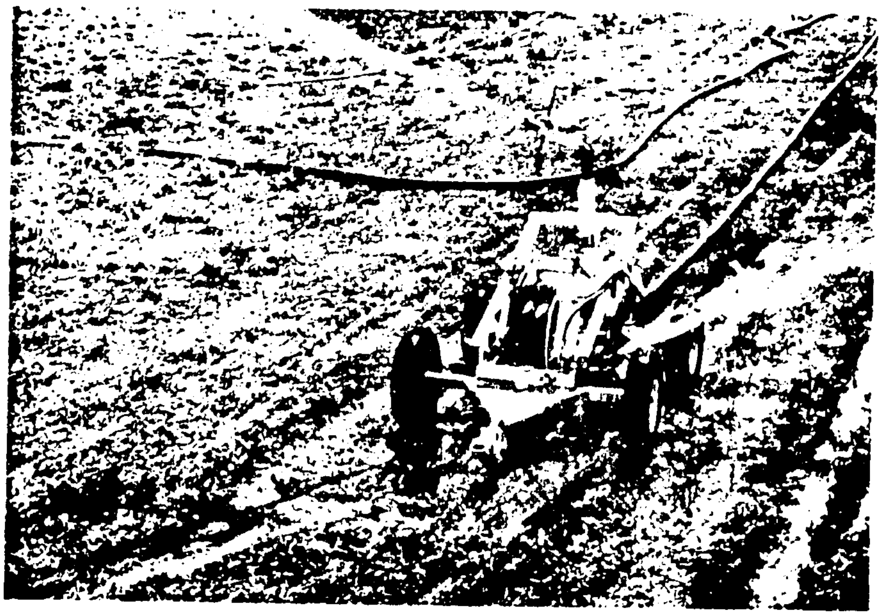


Figure II-5. Giant traveler sprinkler system.

Simple Evaluation - Fixed Grid Sprinklers

The main objectives of the simple evaluation are to identify the more obvious design, operation and management problems or errors.

Equipment needed

An alert and observing evaluator will only need a one to two-gallon container of known volume, a watch with a second hand, a soil probe and a soil auger if available. Soil samples obtained with the auger can be used to aid management in answering the question, "Is it dry enough to irrigate?" However, more sophisticated procedures and equipment can also be used.

Field measurements

Only a few simple field measurements and observations are required.

Operating pressures should be within the medium range for each specific nozzle size and not vary too greatly throughout the system. The medium pressures produce jets with a variety of drop sizes and smooth sprinkler rotation. The large drops travel the furthest and the small drops fall close to the sprinklers which tends to produce uniform coverage when the patterns from several sprinklers overlap.

To aid in spotting excessive pressure variations within a system, a few of the sprinklers should be observed while running at the widest range of pressures available -- high, medium and low. Fogging or irregular turning will tend to result from excessive pressures and many small drops will fall close to the sprinkler. Improper jet breakup causing a doughnut type pattern results from low pressures and very little water will fall close to the sprinkler. The proper pressure within the so called mid-range can only be determined by more extensive evaluation techniques. To maintain a high uniformity of coverage, pressures must also be uniform and gauges should be employed to aid in setting lateral inlet pressures.

Flow rates of several sprinklers should be measured under normal operating conditions to check the uniformity of flow and to determine the average flow rate. Rates should be checked at each end of several lateral lines located at the extremes of elevations and distances. The average rate usually occurs at about 1/3 of the way from the inlet end.

The time to catch a given volume can easily be converted to a flow rate. For example, it if takes 45 seconds to fill a two-gallon container, then the flow rate is 2.0 gal. per 45/60 min. = 2.7 gpm. A typical design limit is to allow a 10% variation of flow between the first and last sprinklers. This corresponds to a pressure variation of 20% which usually does not alter the sprinkler patterns enough to produce poor uniformity.

A check of the flow rates against catalog values will give an indication of pressures which should confirm the field estimates of the correct pressure. Often nozzles are erroded by silt or sand in the irrigation water. This will cause flows to be higher than the initial catalog values. The degree of nozzle erosion can easily be checked with a feeler gauge such as a drill bit of the same diameter.

Uniform application is obtained by properly overlapping sprinkler wetted areas. The amount of overlap required for a given degree of uniformity depends on the nozzle size, pressure, sprinkler operating characteristics and wind conditions. The optimum uniformity, however, is a function of economics which usually results in a compromise between the medium uniformity achieved under a wider spacing and the reduced operating costs and crop returns.

To obtain a medium uniformity, the spacing along the lateral should be close enough for adjacent sprinkler patterns to completely overlap. The spacing between laterals is usually such that for low wind areas one line of sprinklers throws about 2/3 of the distance to the next line. In areas where typical winds exceed 5 mph the lines should be even closer together.

Without making a full evaluation, the uniformity of the sprinkler pattern may be approximated by probing. This is accomplished by probing many spots within the area between two sprinklers on the side of the lateral which was irrigated during the previous set. The areas with minimum infiltration are readily identified, especially late in the season when cumulative soil moisture deficits have had time to build up. This technique will not work if full or excess irrigations are always applied. In such cases, the probe will tend to indicate adequate moisture by deep penetration everywhere.

Management practices

Alternate sets is a practice that tends to greatly improve uniformity. This practice involves setting the lateral midway between previously used sets during every other cycle of hand or mechanically moved systems. It is not applicable to permanent or solid set systems.

Sprinklers should all be erect with the risers perpendicular to the ground. Obviously, the sprinkler nozzles should all be flowing freely and the sprinklers turning uniformly. Maintenance and correct operation are essential for efficient use and where the irrigation water carries trash adequate screening devices are necessary.

Tipping risers at field borders where overlap does not occur is helpful. For the typical condition with the lateral lines from a third to a half move distance from the boundary, some water is thrown out of the field. A practical improvement for crops not damaged by the jet impact is to tip all the risers toward the boundary so the jets just barely reach the edge of the field. This procedure results in fairly uniform coverage along the field boundary (especially where the lateral line is only 1/3 of a move distance inside) and also eliminates much of the objectionable overthrow.

Similar results can be obtained at the ends of the lateral lines by tipping the end sprinkler. This is accomplished by bending the risers. For uniform coverage, these end sprinklers should be set closer than normal to the boundary. A half circle sprinkler with about 2/3 of the standard discharge and operating at the edge of the field is also practical.

Running the sprinklers too long for the existing soil moisture deficiency, smd, is the most common mis-management practice. Such over irrigation is a potential problem except during periods when the full system capacity is required to meet peak use rate demands. The smd should equal the design Management Allowed Deficiency, MAD, at the time of irrigation or the duration of irrigation should be reduced accordingly.

Duration of irrigation can be calculated from the sprinkler application rate, the smd, and an estimate of the Potential system irrigation Efficiency, PE. The first step is to find the average rate of water application, R_a, which is computed by

$$R_a \text{ in./hr.} = \frac{96.3 \text{ x sprinkler gpm}}{\text{sprinkler spacing, ft. x ft.}}$$

Using an estimate of the Potential irrigation system Efficiency, PE, the minimum rate, R_m, at which water is infiltered in the driest 1/8 of the area can be computed by

$$R_m = R_a \text{ x PE/100}$$

and the duration or time of irrigation, T_i, is equal to

$$T_i = \frac{smd}{R_m}$$

For example, assume the PE is 80%, smd is 4.0 in., the sprinkler flow rate is 4.4 gpm, the sprinkler spacing on the lateral is 30 ft. and the lateral move distance is 50 ft. The average application rate is

$$R_a = \frac{96.3 \times 4.4 \text{ gpm}}{30 \text{ ft.} \times 50 \text{ ft.}} = 0.28 \text{ in./hr.}$$

and

$$R_m = 0.28 \text{ in./hr.} \times 80/100 = 0.23 \text{ in./hr.}$$

Then the duration of irrigation

$$T_i = \frac{4.0 \text{ in.}}{0.23 \text{ in./hr.}} = 17.5 \text{ hrs.}$$

If the system is run for 17.5 hours, the Actual application storage Efficiency, AE, would equal the assumed PE of 80%. If the system is run for 23 hours while making one set per day, the last 5.5 hours of watering would be wasted. The AE would be reduced to about 60% and there would be 5.5 hours x 0.28 in./hr. = 1.7 in. of excess deep percolation which would contribute to high water table problems.

A probe can be used to give an indication of when to turn the water off if the above calculations are not possible because the smd is unknown. The probe can be used to follow the wetting front and when the water has penetrated enough for a full irrigation, it should be turned off. (See soil moisture probe, Appendix G.) Taking time to gain sufficient experience to effectively use a probe is most worthwhile. It helps you answer the question, "Is it wet enough to stop irrigating?"

<u>Summary</u>

An experienced observer with a sharp eye and a few quick easy measurements made with very little equipment can obtain much useful information concerning the design and management of a sprinkler system. Operating pressures may be too high or low resulting in poor sprinkler patterns. The flow rate at various places in the system can be compared for uniformity of operations. Flow measurement can also be used to determine the average water application rate which relates to how long the system should be run. Checks to determine when to start and stop each irrigation are excellent guides for good water management. Keeping the mechanical parts in good condition and operating the systems properly is important. Poor water application along the boundaries of a field can often be alleviated by slightly tilting the sprinkler risers toward the field boundary. Running the sprinklers too long, causing excessive deep percolation is common. The correct duration of irrigation can easily be computed from a knowledge of the smd, application rate and PE.

Always keep these two key questions in mind: "Is it dry enough to irrigate?" and "Is it wet enough to stop?"

Full Evaluation - Fixed Grid Sprinklers

The full evaluation procedures which follow do not apply to perforated or nozzle pipe line or giant sprinklers. However, the catch-can pattern may be used for any sprinklers.

Evaluation

The following information is required:

1. Rate of flow from the tested sprinklers.
2. Pressures of the nozzles at the test site and along the laterals.
3. Depth of water caught in the catch containers.
4. Duration of the test.
5. Spacing of the sprinkler along and between the lateral lines.
6. Additional data as indicated on the data form.

Knowledge of the patterns at different pressures and the pressures along the main line and at the pump is also useful. A general study of the field data will permit determination of: Distribution Uniformity, DU; Potential irrigation system Efficiency, PE; Actual application storage Efficiency, AE.

Further study could determine the uniformity and economics of the spacings and/or alternate sets, the economics of main and lateral pipe sizes, the desirability of other operating pressures and durations and the effect of wind.

Equipment needed

1. Pressure gauge (0-100 psi) with pitot attachment. (See Figure II-6.)

Figure II-6. Pressure gauge with pitot attachment for measuring sprinkler pressure.

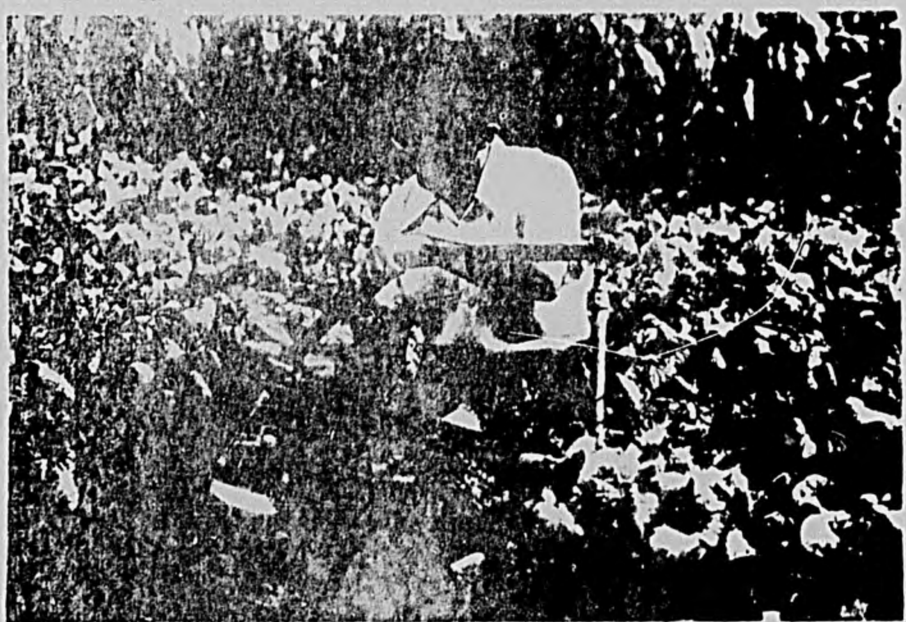


Figure II-7. Measuring sprinkler discharge by means of a hose and a container of known volume.

2. Watch.

3. Bucket of known volume (1 gallon, or larger for large sprinklers).

4. Piece of flexible hose about 4 ft. long. (See Figure II-7.)

5. Catch containers.

6. Measuring stick to measure depth caught in container, or 500 ml graduated cylinder.

7. Soil auger.

8. Tape to layout catch containers.

9. Forms for recording data.

Field procedure

1. Choose a location along a lateral for the test. It may be either a location at which the pressure is typical, or two locations near the ends of a lateral to study effects of pressure differences. As shown in Figure II-8, the pressure loss due to friction in a lateral with one pipe size is such that 50% of the loss occurs in the first 20% of the length, and about 80% in the first 50%. On a flat field, however, the most representative pressure is near the 1/3 point.

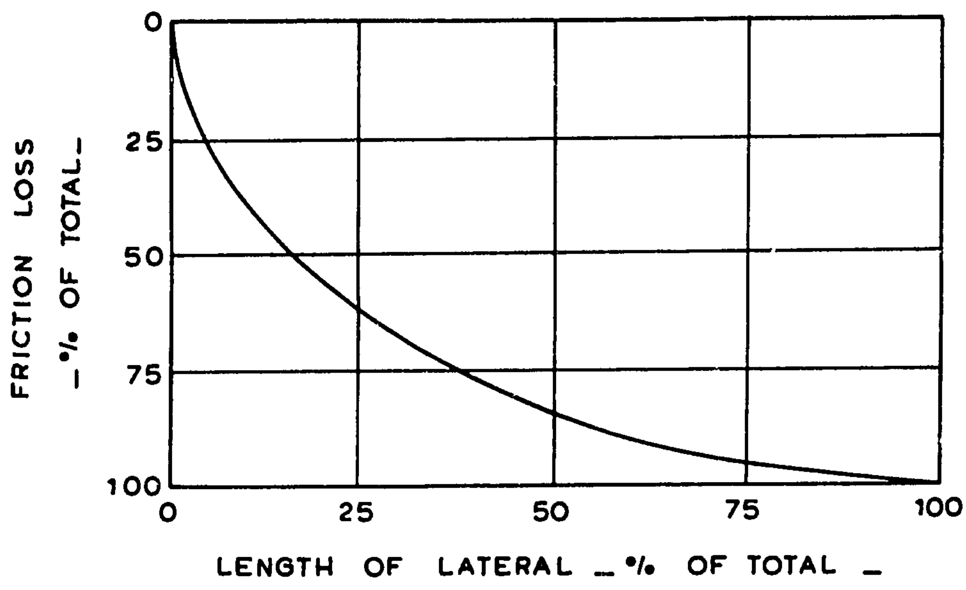


Figure II-8. Friction loss along a lateral with one pipe size.

Where there are large pressure variations within the system, test locations should be selected to cover the range of pressure encountered.

Figure II-9 shows the effect of pressure variation and spacing on DU, with wind velocities of less than 4.0 mph. It also shows the comparison between different nozzle sizes.

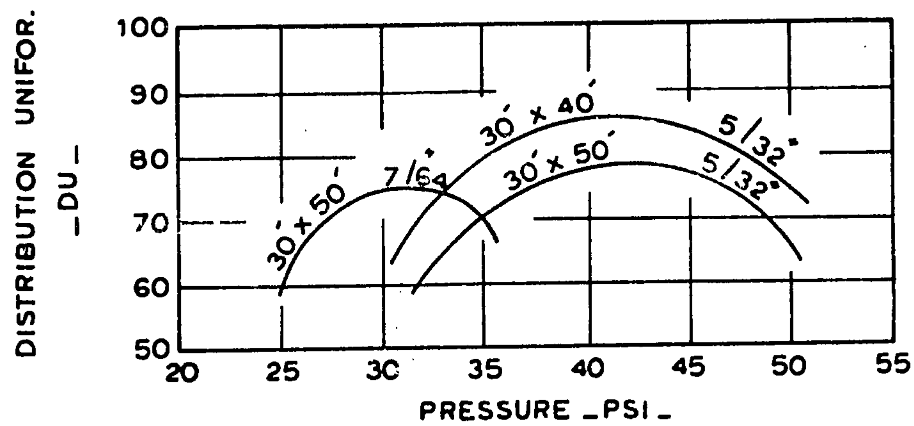


Figure II-9. Variation in distribution uniformity for various pressures, move distance, and nozzle size.

2. Set out a minimum of 24 catch containers on a grid not to exceed 10 ft. by 10 ft. The symetrical pattern should be laid out between two or three sprinklers covering the entire width upon which water may be applied. It is better to cover two adjacent areas between three sprinkler since there are often deviations among the sprinklers. The containers should be layed out as shown in Figure II-10.

For solid set or block move systems where several laterals are operated simultaneously, the catch containers should be placed in the area between four sprinklers. However, such tests cannot be used to study other lateral spacings. The containers should be carefully set in an upright position and the surrounding vegetation removed.

If necessary, the containers may be fastened to short stakes with rubber bands, weighted with a known depth of water (which is later subtracted from the catch), moved a foot or so from their correct positions, or set in shallow excavated holes. Suitable catch containers can be one quart oil cans, plastic freezer containers which are either square or round with slightly tapered sides for nesting, or any smaller container.

3. Set aside a container with the anticipated catch to check the magnitude of evaporation losses.

4. Check sprinkler nozzle size and model, riser height and erectness and lateral pipe size and slope. Stop the rotation of the sprinklers

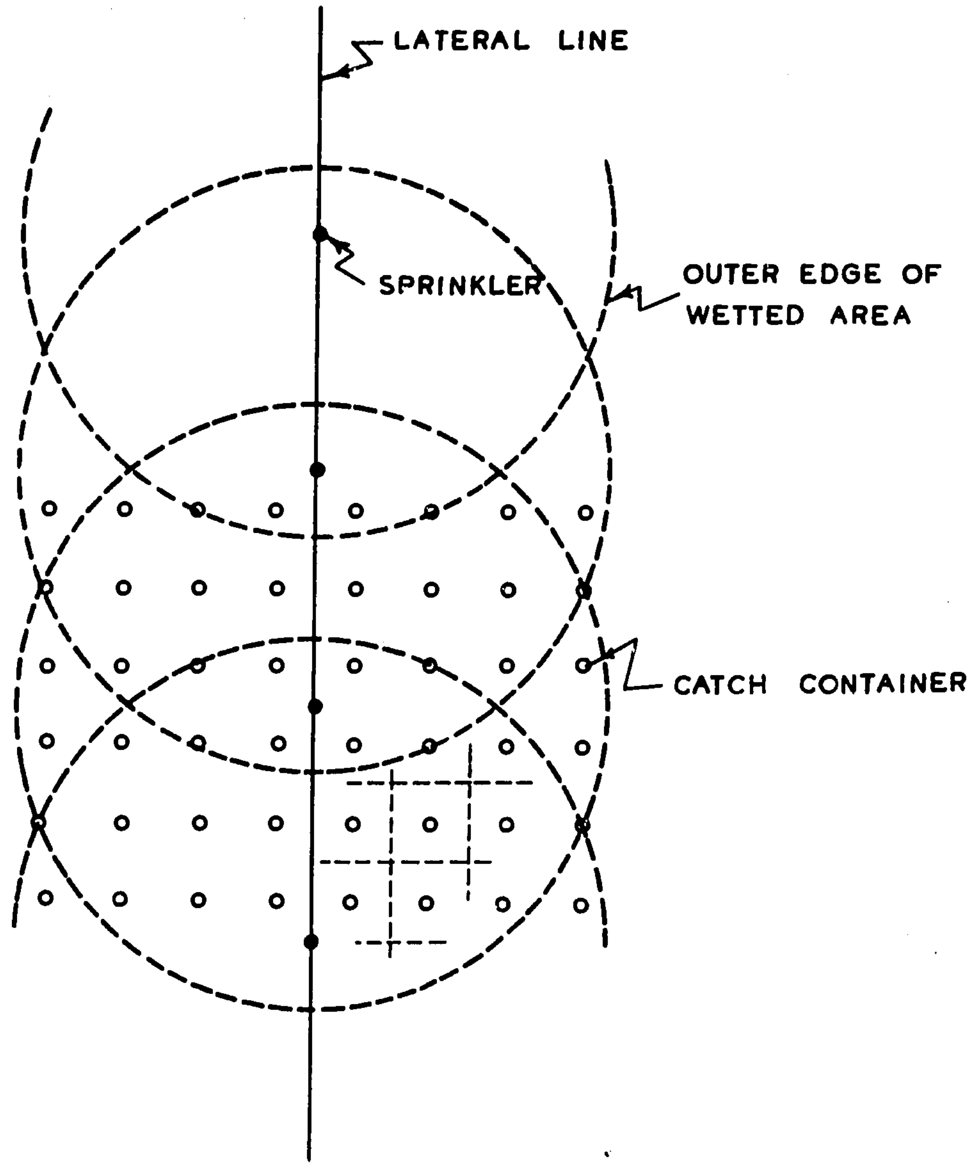


Figure II-10. Catch container layout for Sprinkler Uniformity Test.

surrounding the test site to prevent water from entering the containers until ready. (If the sprinklers are running before the containers are set, direct the jets outside of the test area.)

5. Turn on the water to fill the lateral lines. When the test lateral is full, turn the pressure up slowly to observe the trajectory, drop break-up, and wind effect under different pressure conditions. Then set the pressure at the desired test value.

6. Measure the pressure of the sprinklers to be tested at several places along the line and at the end to observe the pressure variations. When measuring sprinkler pressures (See Figure II-6) the pitot tube must be centered in the jet which must impinge directly onto its tip. The tip

may be rocked slightly and the highest pressure reading recorded while being held about eight inches from the sprinkler nozzles. The pressure, however, should be checked at the beginning and end of the test.

7. Time how long it takes each of the sprinklers in this test area to fill a bucket of known volume. This is done by slipping a short section of hose, which should fit loosely over the sprinkler nozzle, and deflecting the flow into the bucket (See Figure II-7). If the sprinkler has two nozzles, each can be measured separately with one hose. It is not unusual to measure a greater outflow than that listed by the manufacturer at the same pressure because sprinkler nozzles often errode during use. Nozzle errosion can be checked with a feeler gauge such as a drill bit of the same diameter. To improve the accuracy, several measurements should be taken and averaged.

8. Check all catch containers to see that they are empty before the start of the test.

9. Start the test by releasing all the sprinklers surrounding the test site so they are free to rotate, and note the starting time.

10. Note the wind magnitude and direction, temperature, humidity and cloudiness. Wind direction is best recorded as shown on Form II-1 by drawing an arrow relative to the direction of water flow in the lateral.

11. Terminate the test by either stopping the sprinklers surrounding the test site in a position such that the jets do not fall into the containers, or deflecting the jets to the ground. Note the time, check the pressure and turn off the water. It is most desirable for the duration of the test to be equal to the duration of an irrigation to get the full effect of wind and evaporation. Minimum duration tests should apply at least an average of 0.5 in. in the containers.

12. Measure the depth of water in all the containers and observe if they are still upright noting abnormally low or high catches. The best accuracy can be achieved by using a graduated cylinder to obtain volmetric measurements. These can be converted to depths if the area of the container opening is known. For quart oil cans, 200 ml corresponds to 1.00 in. depth. As shown in the sample Form II-1, caught depths or ml are recorded above the line at the proper grid point which is located relative to the sprinkler and direction of flow in the pipe line. For long runs where maximum depths exceed 2.0 in. a measuring stick is suitable for accuracy up to $\pm$ 0.1 inch.

Utilization of field data

The depths or volumes caught in the containers are converted to rates in inches/hour and entered on the data sheet as shown in Form II-1. Assuming that the test is representative and the next set would give identical results, the right hand side of the catch pattern may, as if it were a subsequent set, be overlapped (or superimposed) on the left hand side. For lateral spacings which are whole units of the container spacings, the summation of the catches of the two sets will represent a complete irrigation. See Figure II-11 for an illustration of overlapping. For very close lateral spacings or large wind distortions, water may overlap from as many as four lateral positions. The above concept of overlapping is not suggested where winds are apt to change appreciably between subsequent lateral sets. It is most valid for 24-hour sets.

Distribution Uniformity, DU

In order to determine if the sprinklers are operating at an acceptable and economical efficiency, the deep percolation losses and uniformity of distribution should be evaluated by calculating the Distribution Uniformity, DU. The DU is the ratio of the minimum rate (or depth) caught to the average rate (or depth) caught

$$DU = \frac{\text{minimum rate caught}}{\text{average rate caught}} \times 100$$

Since the lowest rates caught may be the result of tipped containers or variations in reading accuracies, the average of the lowest 1/4 of the catch cans is used as the minimum, thus about 1/8 of the area may receive slightly less water. If the low value were due to a poor field measurement, perhaps no area would actually receive less. The amount of excess water infiltered which is greater than the minimum needed will penetrate below the root zone. If the minimum amount infiltered just matches the soil moisture deficiency, the percent excess going too deep equals (100 - DU).

Figure II-11 shows the data between sprinklers 5 and 6 from Form II-1, overlapped to simulate a 50 ft. lateral spacing. The right side catch is added to the left side catch with the totals at each point representing a complete irrigation for a 30 ft. by 50 ft. spacing.

FORM II - 1. SPRINKLER EVALUATION DATA SHEET

Location: Field [illegible]   Observer: JLM   Date: [illegible] Sept. 19[illegible]

Crop: tomatoes   Soil Texture: c. l.   Surface Runoff: [illegible]

Temperature: [illegible]   Humidity: moderate   Cloudiness: light overcast

Wind direction arrow relative to pipe flow direction   begin: ↘   during: ↙   finish: ↙

Wind magnitude, mph   begin: [illegible]   during: [illegible]   finish: [illegible]

Sprinkler make: R. B.   model: 27 B   nozzles: [illegible]"   x —

Sprinkler rating: pressure: 40 psi   capacity: 4.4 gpm

Riser height: 13"   lateral pipe size: 2"   slope of lateral: 1/2 %

Comments: Test duration too short. Depths caught measured in 1000 ml graduate (500 ml = 100" depth in quart oil cans). Wind velocity [illegible] less than normal.

TEST DATA

Sprinkler spacing: 20'   lateral move: 50'   gauge spacing: 10' x [illegible]

Sprinkler number on the lateral		[illegible]	4	5	6		10	end 12
Sprinkler discharge volume caught		1.0 gal.	1.0	1.0	1.0			1.0
time minutes		.21 min	.22	.22	.22			.22
Rate caught	gpm	4.8	4.6	4.6	4.6			4.6
Pressure begin	psi	45	40	40	40		37	40
Pressure end	psi	45		40			37	40

Evaporation can depth: begin: 2.15"   finish: 2.10"   loss: .05"

Time of test: begin: 2:55 PM   finish: 4:30   duration: 1:35 = 1.58

CATCH DATA IN GAUGE CANS

Show sprinkler number on the lateral. Show computed depth caught / rate in/hr e.g. 3.6" / .30"/hr

catch in ml.

						flow direction						
.	.	32. / .10	68. / .21	77. / .24	90. / .28	S6	73. / .23	66. / .21	9. / .03	ml / "/hr	.	.
.	.	35. / .11	66. / .21	84. / .26	100. / .31		100. / .31	52. / .16	3. / .01	.	.	.
.	.	32. / .10	50. / .16	71. / .22	104. / .32		99. / .31	48. / .15	12. / .04	.	.	.
.	.	31. / .10	74. / .23	88. / .27	104. / .32	S5	86. / .27	56. / .17	11. / .03	.	.	.
.	.	27. / .08	64. / .20	80. / .25	96. / .30		112. / .35	62. / .19	9. / .03	.	.	.
.	.	20. / .06	52. / .16	59. / .19	107. / .33	S4	87. / .27	36. / .11	13. / .04	.	.	.

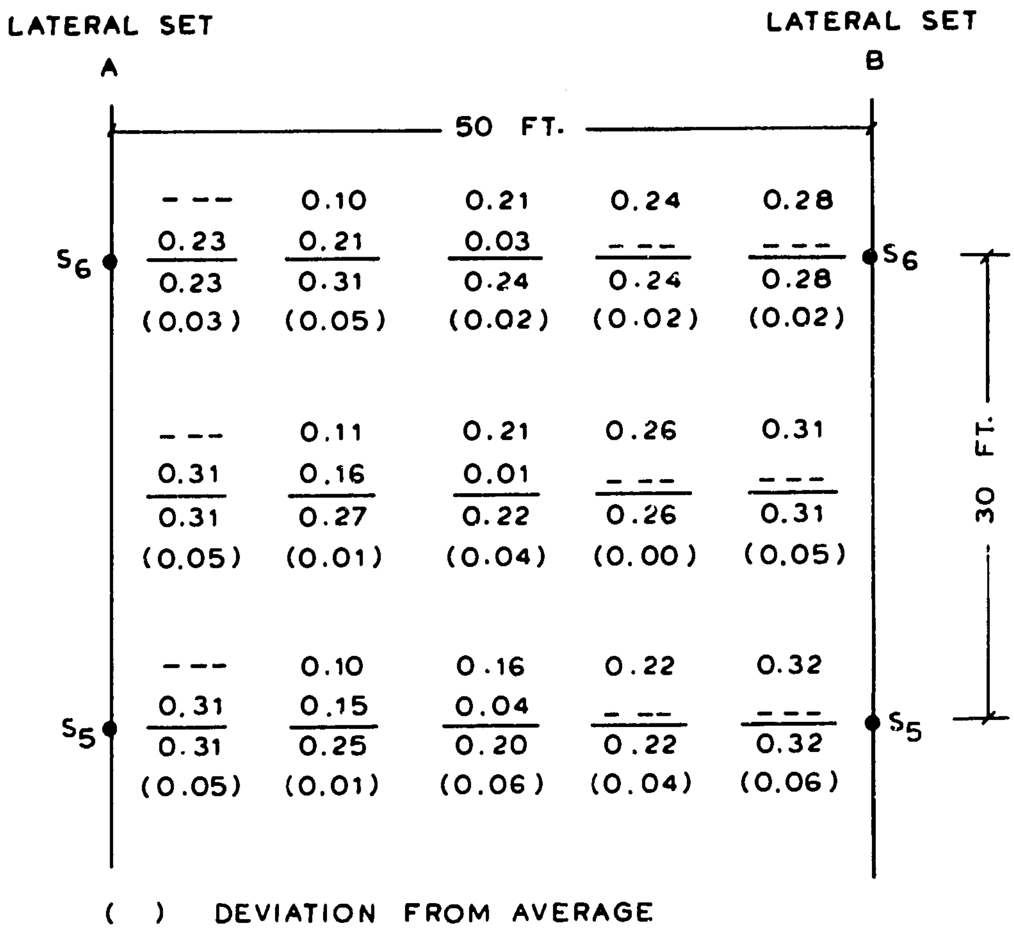


Figure II-11. Combined catch pattern in inches per hour between sprinklers 5 and 6 for a 50 ft. lateral spacing.

The total catch at all 15 grid points is 3.97 in. which gives

$$\text{Av. Catch} = \frac{3.97}{15} = 0.26 \text{ in./hr.}$$

The average of the lowest 1/4 of the cans (use 4 out of 15) is

$$\text{Av. Low } \tfrac{1}{4} = \frac{0.20 + 0.22 + 0.22 + 0.23}{4} = 0.22 \text{ in./hr.}$$

and

$$\text{DU} = \frac{0.22}{0.26} \times 100 = 84\%$$

Repeating the above procedure for a 40 ft. lateral spacing will give

$$\text{Av. Catch} = \frac{3.97}{12} = 0.33 \text{ in./hr.}$$

Av. Low ¼ = 0.27 in.

$$DU = \frac{0.27}{0.33} \times 100 = 82\%$$

Alternate sets. It is usually desirable to use alternate sets in which the lateral line is always placed midway between the position used at the preceding irrigation. This results in a DU for the complete cycle of two irrigations which is the same as if all moves were ½ the normal distance. Figure II-12 shows the combined catch overlapped to simulate a 60 ft. move.

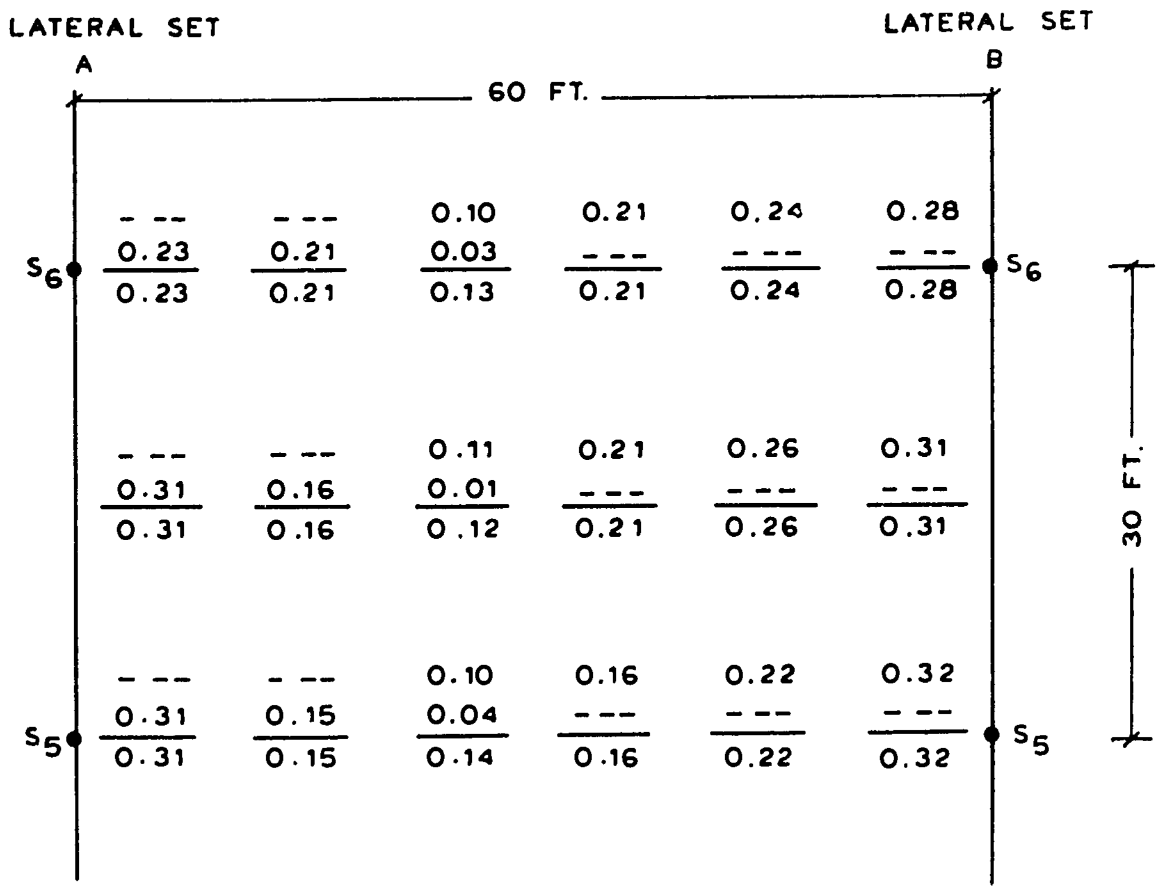


Figure II-12. Combined catch pattern in inches per hour between sprinklers 5 and 6 for a 60 ft. lateral spacing.

The total catch in the 18 cans is 3.97 in. as before:

$$\text{Av. catch} = \frac{3.97}{18} = 0.22 \text{ in./hr}$$

$$\text{Av. low } ¼ = \frac{.12 + .13 + .14 + .15}{4} = 0.14 \text{ in./hr.}$$

$$DU = \frac{0.14}{0.22} \times 100 = 64\%$$

Figure II-13 shows the right half (3 columns) of Figure II-13 superimposed on the left half to simulate two irrigations with 60 ft. moves offset half way, i.e., 30 ft. Since each side of the new pattern will be identical, only 30 ft. of the pattern needs to be computed from the already combined values for the 30 ft. by 60 ft. spacing presented in Figure II-12. The data in Figure II-13 represents the catch from two one-hour sets.

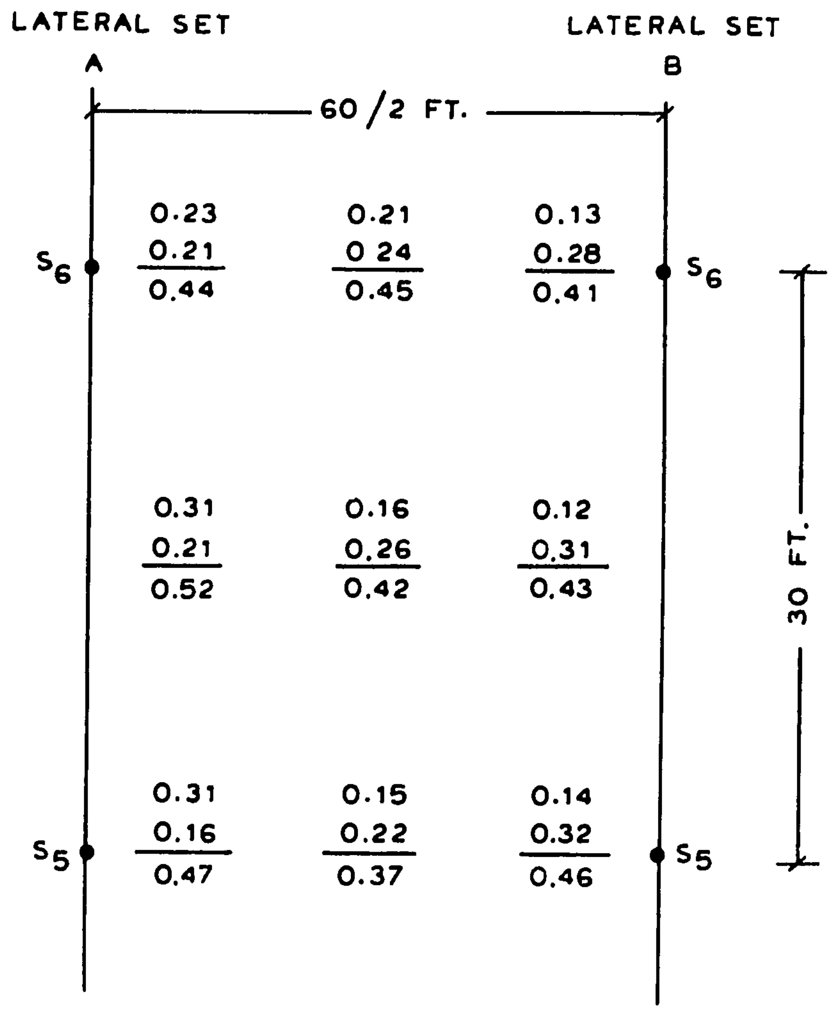


Figure II-13. Combined catch pattern in inches per hour between sprinklers 5 and 6 for a 60 ft. lateral spacing offset 30 ft. for a second irrigation.

Again the total catch in the 9 cans for two irrigations is 3.97 in.

$$\text{Av. catch} = \frac{3.97}{9} = 0.44 \text{ in./2 hrs.}$$

$$\text{Av. low } \tfrac{1}{4} = \frac{.37 + .42}{2} = 0.40 \text{ in./2 hrs.}$$

$$\text{DU} = \frac{0.40}{0.44} \times 100 = 91\%$$

It is interesting to note that the simple management program of alternate sets improved the DU from a low of 64% for a single irrigation, to 91% for the sum of two irrigations. The alternate set procedure will not overcome an inadequate irrigation depth between the laterals which would excessively stress the crop during the intervals between the two full irrigations. A moderate under-irrigation in the mid-area is not detrimental if adequate moisture is applied in the upper portion of the root zone and frequent irrigations are employed, since the deficiency from the first irrigation will occur at the bottom of the root zone from which very little moisture is extracted.

Coefficient of uniformity, Cu

A common way to present sprinkler uniformity is the Cu, which is a statistical representation of the catch pattern. When expressed as a percentage, it is calculated by

$$\text{Cu} = \left(1 - \frac{\text{average deviation from the average catch}}{\text{average catch}}\right) \times 100$$

From Figure II-11 the summation of the deviations, from the average catch of 0.26 inches, is 0.51 inches. Since there are 15 grid points, the average deviation is 0.51 in. divided by 15, and it follows that

$$\text{Cu} = \left(1 - \frac{0.51}{0.26 \times 15}\right) \times 100 = 87\%$$

Applying DU and Cu

The DU is computed using the average depth of catch in the *low quarter* of the pattern. The Cu computed from the same data would be considerably higher, since it is more nearly related to the average depth in the *low half* of the pattern. Table II-1 gives the average statistical relationship between Cu and DU, so either value can be approximated from the other. To achieve high uniformity values close sprinkler spacings are generally required. In general, the closer the sprinkler spacings, the higher the system costs.

Table II-1. Average relationship between Cu and DU.

Cu	DU	Cu	DU
Percentage		Percentage	
98	97	80	66
96	93	76	60
92	87	72	54
88	80	68	49
84	73	64	44

For high value crops, especially those with shallow roots, the most economical systems usually have high uniformities, i.e., DU above 80% (or Cu above 88%). For typical field crops with medium root depths and soils the most economical uniformity normally ranges between a DU of 70 and 80% (a Cu between 82 and 88%). For deep rooted orchard and forage crops and where there is a substantial quantity of supplemental rainfall, the most economic uniformity is often relatively low being in the range of DU between 50 and 70% (a Cu between 70 and 82%).

Potential irrigation system Efficiency, PE

The PE should be determined in order to evaluate how effectively the system can utilize the water supply and what the total losses may be. Then the total amount of water required to fully irrigate the field can be estimated. The PE is calculated by

$$PE = \frac{\text{min. rate caught}}{\text{av. rate applied}} \times 100$$

The difference between the water applied and the water caught is an approximation of evaporation and drift losses plus water loss due to some of the area being ungauged. (Rate rather than depth should always be used for computing PE to avoid confusion with AE). The PE indicates how well the tested sprinklers are able to operate if they are run the correct length of time to just satisfy the smd. It is, therefore, a measure of the best management can do and should be thought of as the potential of the system.

The average water application rate in inches per hour is computed from the sprinkler discharge in gpm and the sprinkler and lateral line spacings in feet by

$$\text{Application rate} = \frac{96.3 \times \text{gpm}}{\text{ft.} \times \text{ft.}} = \text{in./hr.}$$

From Form II-1 the average discharge of the sprinklers tested was 4.6 gpm. Therefore, the application rate for a 30 ft. by 50 ft. spacing is

$$\text{Application rate} = \frac{96.3 \times 4.6}{30 \times 50} = 0.30 \text{ in./hr.}$$

For the area between sprinklers 5 and 6 and a 30 ft. by 50 ft. spacing, where the average catch in the low quarter of the cans was 0.22 in./hr.

$$\text{PE} = \frac{0.22}{0.30} \times 100 = 73\%$$

Tables II-2 and II-3 give a summary for DU, Cu and PE computations with various lateral spacings, for the area between sprinklers 5 and 6 and the area between sprinklers 4 and 5, computed as above from the data presented in Form II-1.

Table II-2. Summary of efficiencies for various move distances for the area between sprinklers 5 and 6.

	Spacing in Ft.			
	30 x 40	30 x 50	30 x 60	30 x 60 alt.
DU	81	84	64	91
Cu	87	87	75	93
PE	73	73	56	81

A comparison of values given in the tables illustrates the problem of choosing a typical or minimum site. It should be assumed that there are other sites in the field which are poorer as well as better than the tested site; therefore, computed efficiencies are not exact although they are useful for evaluating the system.

Table II-3. Summary of efficiencies for various move distances for the area between sprinklers 4 and 5.

	Spacing in Ft.			
	30 x 40	30 x 50	30 x 60	30 x 60 alt.
DU	79	76	50	82
Cu	86	88	70	91
PE	70	67	44	72

Actual application storage Efficiency, AE

The effectiveness of the use of the sprinkler system can be determined by how much of the applied water is stored in the soil and available for comsumptive use. If an inadequate irrigation is applied the AE may be very high, since only the water which evaporates may be lost if none goes too deep. If excess water is applied, however, much of it may go too deep and be lost resulting in an AE considerably lower than the PE. (The DU and PE values may not be affected by the depth applied.)

The units for calculating AE are given in terms of depths, but not rates, since the maximum depth stored cannot exceed the smd which equals the depth of water that can be stored. The AE is calculated by

$$AE = \frac{\text{min. depth stored in the root zone}}{\text{average depth applied}} \times 100$$

For this test the normal irrigation was for 23.5 hours. With the 30 ft. by 50 ft. spacing the average application rate was 0.30 in./hr. and the total average depth applied was

$$D_{av} = 0.30 \text{ in./hr.} \times 23.5 \text{ hrs.} = 7.0 \text{ in.}$$

The minimum rate caught was 0.22 in./hr. (Or alternatively, with PE = 73%, = 0.30 x 73% = 0.22.) Therefore, the "minimum" depth infiltered was

$$D_{min.} = 0.22 \text{ in./hr.} \times 23.5 \text{ hrs.} = 5.2 \text{ in.}$$

It was determined that the soil holds about 2.2 in./ft. of available moisture, the root zone depth was 4.0 ft. at that time, and a 50% Management

Allowed Deficiency, MAD, which will not excessively stress the crop is considered acceptable. At the time of irrigation, the smd should be checked to see if it is at the desired deficiency of 2.2 in. x 4.0 ft. x 50% = 4.4 in., since the amount stored cannot be greater than the existing smd. The sprinklers as tested were applying 5.2 in. in 23.5 hours, which is more than enough. This gives an AE of

$$AE = \frac{4.4}{7.0} \times 100 = 63\%$$

It should also be noted that this is considerably less than the PE of 73% and could be improved by reducing the application time so that PE = AE.

Analysis and recommendations

A number of observations and recommendations can be made from the information on the Sprinkler Evaluation Data Sheet, Form II-1, the summaries of computations in Tables II-2 and II-3 and the value of AE.

The pressures along the lateral line are very uniform since the ground which slopes down at 15% for 420 ft. drops 6 feet which compensates for much of the pressure loss.

The typical sprinklers location on the lateral can be assumed to be between sprinklers 4, 5 and 6 since the pressure is very uniform. Tests at other pressures were not made although they might show a pressure change would be desirable. (See Figure II-9.) Since the test was short and longer tests usually produce higher DU and PE values, except where a sprinkler is defective, the higher values from Table II-2 were used rather than averaging the two tables.

Water losses. Other than deep penetration, water losses are indicated by the differences between the average rates applied and caught. This includes drift and other losses in the air, water falling on ungauged areas and evaporation and other losses (or additions) from the containers. Evaporation losses from the droplets as they pass through the air are related to humidity, air and water temperature, wind speed and drop size. Such losses typically range from 2 to 15% being lowest at night. Drift is related to wind velocity and drop size and may range from negligible to above 5%. The fact that the wetted perimeter seldom coincides with the line midway between grid points typically results in an average can catch which is about 2% low. Evaporation from the open catch containers, however, can exceed 0.4 in./day. It will be a greater percentage of the catch along the edge of the pattern than from near the sprinklers where the catch is deeper and the containers are also wet more on the outside. The magnitude of this evaporation loss can be estimated by the water loss from a container set adjacent to the test area as described earlier. Clouds, wind and humidity have major effects on the direct evaporation losses from the containers. When using the volumetric procedure to determine the depths of catch as was done for the sample evaluation, some water clings to the can walls and remains unmeasured. The fact that some of the containers may be tipped and thus catch more or less than their share also adds to the inaccuracy of measurements. Since it is impractical to precisely measure both the water applied and the water caught, the amount of water unaccounted for is only an approximation. For the 30 ft. by 50 ft. area between sprinklers 5 and 6, the average rate caught was 0.26 in./hr. and the average rate applied was 0.30 in./hr. Therefore, rate unaccounted for was 0.04 in./hr. or (0.04/.30) x 100 = 13%. The accuracy of these measurements, as well as that from the evaporation can for the short test, i.e., 0.05 in./1.58 hr. = 0.03 in./hr. (see Form II-1) were such that the evaporation can incorrectly accounts for almost the entire computed loss.

Improvements. Several improvements may be considered even though some may not be practical or economical.

1. The move distance of 50 ft. presently being used is acceptable as far as uniform distribution is concerned, since DU is above 80%. (The corresponding value of Cu, which is above 85%, is also considered as reasonable.)

2. A 60 ft. lateral move with alternate sets is appreciably more efficient than the 30 ft. by 50 ft. spacing being currently utilized, i.e., from Table II-2, PE = 81% rather than 73%. The 60 ft. move would also reduce labor by nearly 20%.*

Alternate set irrigation will usually improve DU and PE, but unless the hours of operation are reduced, or MAD increased, there would be no improvement in AE.

3. The duration of application can be reduced so that only 4.4 in. is applied. The minimum application rate for the 50 ft. lateral spacing

*At the resulting reduced average application rate of 0.25 in./hr., an adequate irrigation of 4.4 in. would be completed in 22 hours, i.e., 0.25 x 81% x 22 = 4.4 in. Although the original MAD could be increased to 5.2 in., only 4.8 in. would be applied in the maximum 23.5 hour set. Therefore, the frequency could not be decreased to minimize labor. However, water would be saved by having the higher PE and irrigating at a lower smd.

is 0.22 in./hr., so the proper duration = 4.4/0.22 = 20 hours. The change to a 20-hour operation instead of 23.5 hours may be easily accomplished by turning the system off; however, it may be impractical if a constant flow is being delivered from a ditch and no reservoir is available. On some installations, an automatic time activated cutoff may be installed. Where less than 24 hr./day operation is used it may also be practical to schedule the shut off time to avoid a windy period.

4. The rate of application can be reduced to obtain the desired duration and depth relation by either reducing pressure or using smaller nozzles. These changes will affect DU and PE and require further testing.

Pressure can be reduced by throttling which may save water unless DU becomes much lower, but will usually not reduce power cost. However, the pump speed or impeller diameter may be changed thereby saving both water and power.

Smaller nozzles may require a change in pressure. For example: a 9/64 in. nozzle at 45 psi delivers 3.7 gpm applying an average of 0.24 in./hr. on a 30 ft. by 50 ft. spacing. With a PE of 77%, the system will apply a minimum of 4.4 in. in 23.5 hours. A test would be needed to check the PE, but from Figure II-9, 77% appears reasonable.

5. It would be possible to increase AE by increasing the interval between irrigations so that the smd at which irrigation is applied is 5.2 in. The MAD would then be 5.2/(4.0 ft. x 2.2 in./ft.) = 60% instead of 50% as previously chosen. For many crops this would not result in a detrimental stress and would be the most practical answer for saving both water and labor.

<u>Summary</u>

The test area was typical of the whole lateral, since pressures were very uniform along the line. Furthermore, the lateral on which the test was conducted was typical for the whole system. Tests at lower pressures or with 9/64 in. nozzles would be desirable for evaluating the fourth improvement presented above.

The duration of the test was short (1.5 hrs.) so depth measurements were calculated from volumetric data to obtain acceptable accuracy.

Two adjacent test areas gave significantly different DU, Cu and PE values.

The DU and PE were reasonably high and indicated that the system was capable of providing efficient irrigation.

Water losses under the test condition were about as low as could be expected.

For the desired MAD of 4.4 in., the designed 23.5-hour duration was too long and resulted in a low AE. This may be corrected by operating only 20 hours; by reducing nozzle size and re-checking DU and PE; by operating at a lower pressure which probably would result in a low DU and PE and definitely should be re-evaluated; by using 60 ft. alternate set moves which would save labor as well as water and should be the first choice if practical; or by increasing the MAD to 5.2 in. (60%) which should be acceptable for mature tomatoes.

Field variations and measurement inaccuracies, particularly smd do not permit a high degree of accuracy. However, the field evaluation and analytical technique presented above are useful for defining system design and management problems.

Further evaluation

In addition to checking the AE and ways for improving it, an economic study may also be valuable. Where pressure is created by pumping, the pressure loss in the pipe lines and/or the cost of higher pressure to increase capacity may be uneconomical. A general rule of thumb which also gives good uniformity, but not necessarily good economics, requires that the pressure drop due to friction and elevation in the lateral be less than 20% of the average design pressures. This results in about 10% range in sprinkler discharge rates and about 2% excess water over the average application. The lateral inlet pressure should be the design pressure plus 3/4 of the pressure difference due to friction loss. This can be seen by referring to Figure II-8.

The following example illustrates the economics. In Form II-1 the inlet pressure was 45 psi and all other tested pressures were very close to the desired 40 psi for the 2 in. lateral line tested.

A study to compare the losses in a 3 in. pipe shows that the inlet pressure would be 39 psi and the pressure along the line and at the end would average 40 psi, since the slope more than compensates for friction losses. The economic value of the 45 - 39 = 6 psi savings in terms of reduced power costs would need to be compared with the increased annual ownership cost of the larger pipe. There would also be a small savings of water due to the more uniform pressure. The same principle can be applied to pressure loss along the main line. The problem of achieving uniform watering along the boundaries of fields can often be solved by tipping sprinklers. Since sprinklers depend on overlap to apply an adequate depth of water between lines, an adequate depth is usually applied along the edge of fields where there is no overlap. In established crops the sprinkler range may be reduced and water concentrated along the edge by tipping the risers to shorten the distance of throw. On the end of the lateral, the last sprinkler can be set back about a quarter of its throw diameter from the downstream boundary and the riser bent downstream. Along the edges of the field parallel to the laterals, the whole line must be tipped (or rolled). This should only be done to established crops, because of the increased jet impact caused by tipping could damage young seedlings. Since pressure differences exist throughout the pipeline network, adjustable valves should be provided at each lateral inlet and the inlet pressure set to the desired value. Where maximum pressure variations in a lateral are too large, due to topography, flow or pressure regulators may be installed in the risers to establish a relatively uniform flow rate for all sprinklers.

Maximum rates of application usually occur close to the sprinklers although the maximum combined depth may be elsewhere. The maximum rate, which does not vary with the move distance should not exceed the soil intake rate. Sometimes where runoff is a problem, infiltration can be improved by increasing the operating pressure. This reduces the instantaneous application rate and drop size although the average application rate will be increased. If increasing the operating pressure is impractical or unworkable, nozzle sizes must be reduced.

Orchard Sprinklers

This section will cover the procedures for evaluating under-tree non-overlapping (or slightly overlapping) patterns with portable or solid set sprinklers. The uniformity of overtree sprinklers, useful for frost protection and climate control as well as for irrigation, can only be evaluated at the tree canopy level. The interference of the catch pattern by the trees makes soil surface measurements impractical. However, it is the ground level distribution that is important for irrigation. Observations will give some idea of how much is dry and probing will give an indication of uniformity. Under-tree systems requiring overlap from adjacent sprinklers to obtain uniformity can be evaluated by the standard open field evaluation technique described in the above previous section.

Some potential problems relative to orchard sprinklers which should be considered when selecting the equipment are: 1. does wetting the soil around the tree trunk induce diseases and would a shield give the trunk sufficient protection; 2. will the spray cause fruit damage; 3. do low branches and props seriously interfer with the pattern uniformity; 4. does salinity of the water cause damage to wetted leaves and is the water supply sometimes inadequate so that it is desirable to use sprinklers which can be adjusted to wet a smaller area when necessary?

Evaluation

The data needed for evaluation of an existing under-tree non-overlapping system consists of determining the:

1. Depth or volume of water caught in a radial row (or rows) of catch containers from several sprinklers.
2. Duration of test.
3. Duration and frequency of normal irrigation.
4. Flow rate from tested sprinkler.
5. Flow rate and pressure at several other sprinkler locations.
6. Soil moisture deficiency, smd, and Management Allowed Deficiency, MAD.
7. Sprinkler locations relative to trees.
8. Spacing of tree arrangement and size.

9. Sequence of operation.
10. Percent of area wetted.

Equipment needed

The equipment needed is essentially the same as for the full evaluation of fixed grid sprinklers listed on page II - 9. However, a pressure guage is not absolutely essential and only 10 to 15 catch containers are needed.

Field procedure

The information obtained for the following field procedure should be entered in a data sheet similar to the one shown as Form II-2.

1. Choose radial row locations where water will only be caught from one sprinkler. It is best to test several sprinklers at different locations to check for system variations and improperly adjusted sprinklers. Fortunately, to save time it is practical to simultaneously test several sprinklers with different adjustments and pressures.

2. Determine the soil texture and profile, and estimate the available soil moisture capacity of the soil and root zone.

3. Make a smd check in the area of the pattern which will receive a full depth of irrigation. This area should represent about half or more of the sprinkler pattern and not be affected by overlap or tree drip.

4. Note the tree spacing pattern and the location of the sprinklers relative to the trees.

5. Note the nozzle size, riser height, jet trajectory height, and sprinkler rotation characteristics.

6. Observe sprinkler operation at higher and lower pressures, then set the pressure back to "normal" to make the evaluation test.

7. Measure the discharge of the test sprinkler including any leakage. Overall system uniformity can be evaluated better by flow rate determinations than pressure checks; however, a knowledge of pressures is desirable.

8. Set out a radial row of catch containers as shown in Figure II-14 in an upright position. If unusual conditions such as wind or steep slope exist, four symetrical rows of containers should be used; however, if wind is negligible, as it often is in orchards, one row is adequate. Remove any potential interference due to weeds, branches, props, etc. Space the first container 1.0 ft. from sprinkler, and the rest 2.0 ft. apart to cover the full range of the jet.

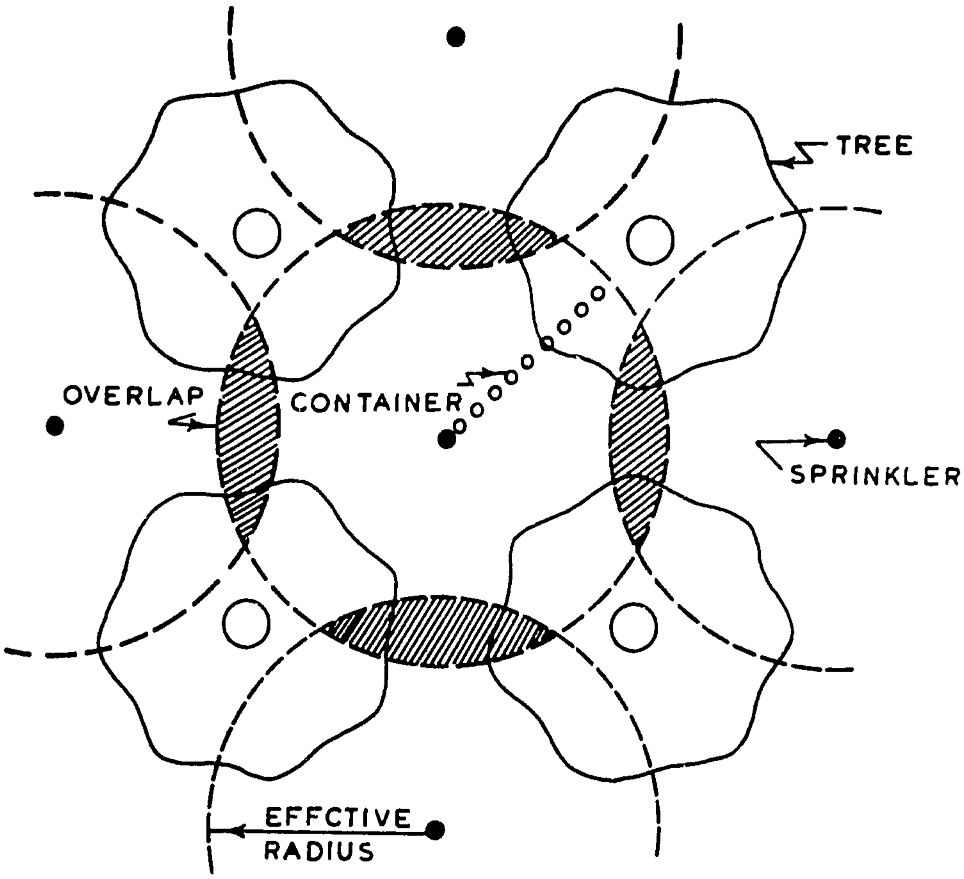


Figure II-14. Layout for orchard sprinkler test.

9. Note the starting time of each test, being sure that all containers are empty.

10. Note operating conditions such as wind, impact on trees and resulting drip, overlap on next sprinkler patterns if any, uniformity of rotation, etc.

11. Terminate each test and note the time. If practical continue each test for a full irrigation, (watch out that containers don't overflow) or until at least 1.0 in. is caught in some containers.

12. Measure and record the depth or volume caught in each container.

13. Use the soil probe at end of test to check the pattern. At the end of a normal irrigation andagain one or two days later, check the penetration in various parts of the pattern to assure that an adequate depth has infiltered.

FORM II - 2. ORCHARD SPRINKLER EVALUATION DATA SHEET

Location ________ observer *JLM* date *17 June 73*

Soil texture *sandy loam*, profile *deep uniform*, available moisture *1.6* in./ft.

root zone depth *5.0*, MAD% *50*, MAD inches *4.0*, smd inches *4.0*

Type of system *3 head hose pull, alternate side*, crop *apples*

Tree interference *negligible*, wind *negligible*

Tree spacing *24* x *24*, tree pattern *square*

Comments *200 ml = 1.00" depth in quart oil cans*

Sprinkler: make ________, model ________, nozzle size ________

Sprinkler flow rate *54/60* x *–* min./gal.; *1.1* + *–* = *1.1* gpm

Sprinkler height *12"*, jet height *40"*, pressure *—*

Time: start *7:20 pm*, finish *8:00 am*, duration *12.7* hours

Farm irrigation: duration *24* hours, frequency *21* days

Average rate applied $= 96.3 \frac{\text{gpm}}{\text{area}} = 30.6 \frac{\text{gpm}}{\text{radius}^2} = 30.6 \frac{1.1}{13.3^2} =$ *.19* in./hr.

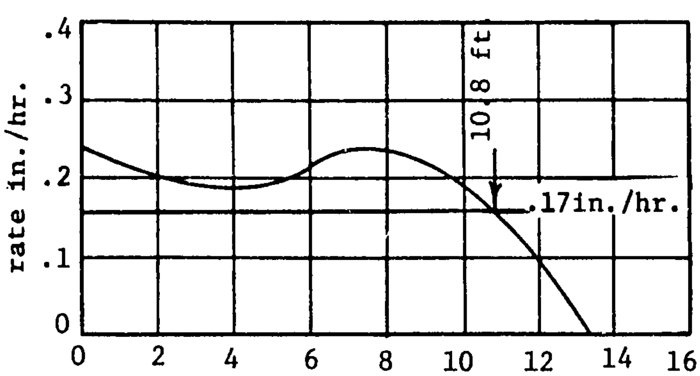
Average rate caught (infiltered)

			effective radius		quarter radius	rate
inner quarter	40%	x	*13.3*	=	*5.3*	*.20*
second quarter	60%	x		=	*8.0*	*.22*
third quarter	78%	x		=	*10.4*	*.18*
~~outer quarter~~	93%	x		=	*12.3*	*.08*
					total	*.68*

÷ 4 = *.17* in./hr. infiltered

Instructions:

1. Enter below the radial distance, the depth or volume caught in container
2. Compute rate of catch for each location.
3. Plot rates at each location and resulting rate profile.
4. Note effective radius where rate profile is zero. Enter in table.
5. Compute radius for center of each quarter area. Enter in table.
6. Note and enter in table rate at radii in number 5.
7. Sum the rates in all four quarters and divide by 4 to get average rate caught.



	2	4	6	8	10	12	14	16
depth	*2.8*	*2.4*	*2.5*	*2.9*	*2.8*	*2.1*	*.5*	—
rate	*.22*	*.19*	*.20*	*.22*	*.22*	*.16*	*.01*	—

Distribution Characteristic is % area wet at average rate

Radius at average rate *10.8*

Radius Ratio = average/effective = *10.8 / 13.3* = *.81*

$DC = (RR)^2 \times 100 = (.81)^2 \times 100 =$ *66* %

radial distance, feet depth, or volume rate, in./hr.

Utilization of field data

The recorded field information should be reduced to a form which can be conveniently used and studied. The depths or volumes caught should be converted to rates in inch/hour the rate profile plotted as shown on the sample Form II-2 and the effective radius noted.

From the effective radius of 13.3 ft. the radius at which the approximate average rate occurs for each concentric quarter of the area, can be computed as demonstrated on Form II-2. For example, the radius at which the average rate occurs in the outer quarter is at 93% of the effective radius, i.e., 0.93 x 13.3 ft. = 12.3 ft. An approximation of the average rate caught over the total wetted area is the sum of the rates at the quarter points divided by four, i.e., (0.20 + 0.22 + 0.18 + 0.08)/4 = 0.17 in/hr. It is usually assumed that the water caught is equivalent to the water infiltered.

Distribution Characteristic, DC. For a single non-overlapping sprinkler, DC is the percent of the total wetted area that has infiltered more than the average depth. It is determined as illustrated on Form II-2 by first drawing a line representing the average rate of a 0.17 in./hr. across the rate profile line and noting the radius of 10.8 ft. where the two lines cross. Then calculating the ratio of this radius to the total radius and multiply the square of the ratio by 100 as follows

$$\text{Radius ratio} = \frac{10.8}{13.3} = 0.81$$

and:

$$\begin{aligned} DC &= (\text{Radius Ratio})^2 \times 100 \\ &= (0.81)^2 \times 100 = 66\% \end{aligned}$$

The DC relates to the uniformity of that portion of the central wetted area that may contribute to deep percolation losses even under good management. High DC values indicate that potential deep percolation losses are low and the adequately irrigated area may be relatively large. The DC can approach 100% which indicates an extremely uniform application, providing there is very little overlap or tree interference. A DC greater than 50% is considered satisfactory and the example problem's value of 66% indicates a very good pattern.

<u>Application storage Efficiency, E_a.</u> In the area wetted the E_a should be determined so that the effectiveness of the irrigation can be evaluated. The AE cannot be used for orchard systems which only wet part of the area since the minimum depth would be zero.

$$E_a = \frac{\text{average depth stored}}{\text{average depth applied}} \times 100$$

In computing the *average depth stored* it is assumed that all the water which falls on each spot within the wetted area up to the smd is stored. Water in excess of the smd is lost to deep percolation. The following procedure is presented to aid in the calculation of the average depth stored:

First determine the depth that would be applied at each catch point by multiplying the rate values calculated on Form II-2 by the duration of a normal irrigation, which for this example is 24 hours. Then plot the depths of application as shown in Figure II-15 and draw a line across the depth profile representing the smd. For this illustration the smd equals 4.0 in. and is assumed to be uniform. All moisture above the smd line will be stored in the soil. (Overlap and/or distortions caused by the trees are not included.)

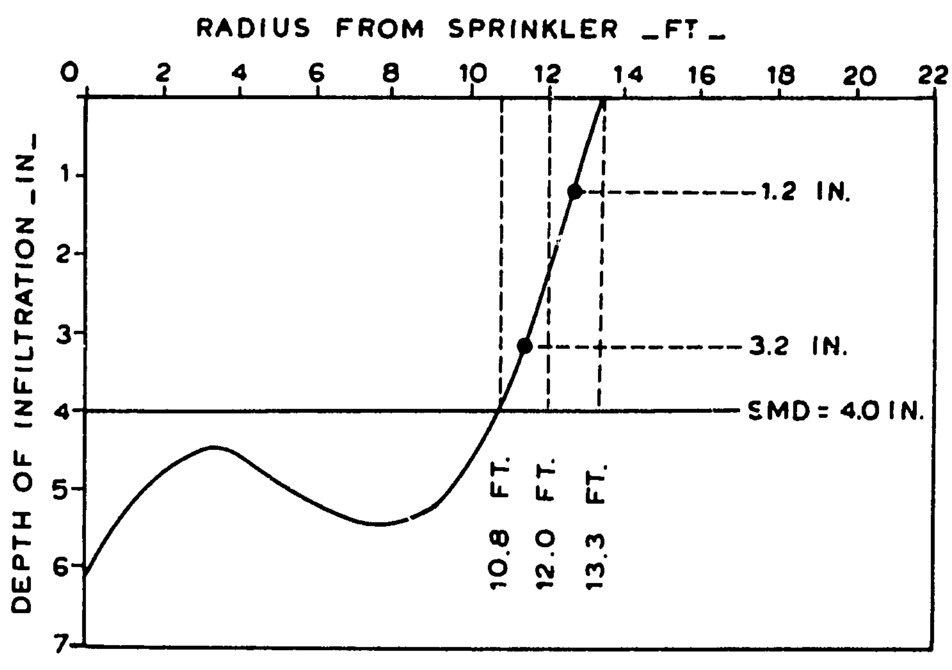


Figure II-15. Water application profile for 24-hour set.

To determine the average depth stored above the smd line multiply the average depths infiltered into various portions of the area by the portion of the area receiving that depth. The sum of these products will equal the average depth stored. The entire area inside the radius at the intersection between the smd and the depth profile will store the smd. With a fairly uniform profile, one average value is adequate for the area beyond the smd line intersection; however, with more curving profiles, two areas will give better results. For Figure II-15, one outer section would be adequate but two are used for demonstration. The steps used to calculate the average depth along with numerical values based on Figure II-15 are:

1. Find the radius at the smd intersection with the depth profile (10.8 ft.) and one other radius (12.0 ft.) dividing the under-watered profile into two convenient sub-areas.

2. Determine the ratio between these radii and the effective radius of 13.3 ft., (10.8/13.3 = 0.81, 12.0/13.3 = 0.90).

3. Find the corresponding percent area included inside each radius $(0.81)^2 \times 100 = 66\%$, $(0.90)^2 \times 100 = 81\%$).

4. Determine the percent of the total area of each of the three sub-areas defined by the two intermediate radii. For this example, they are 66%, 81 - 66 = 15%, and 100 - 81 = 19%.

5. Estimate the average depth in each sub-area from the depth profile (these can be taken at the middle of each sub-area with adequate accuracy). From Figure II-15, these are the smd of 4.0 in., 3.2 in. and 1.2 in.

6. Multiply each sub-area percent by the corresponding average depth. The sum of the products divided by 100 is equal to the average depth stored.

$$
\begin{aligned}
0.66 \times 4.0 &= 2.6 \text{ in.} \\
0.15 \times 3.2 &= 0.5 \\
0.19 \times 1.2 &= \underline{0.2} \\
\text{Total} &= 3.3 \text{ in.}
\end{aligned}
$$

The *average depth applied* is computed by beginning with the average sprinkler discharge rate of 1.1 gpm and the wetted radius to obtain

$$\text{Application Rate} = \frac{96.3 \times \text{gpm}}{\text{wetted area}}$$

$$\text{Application Rate} = \frac{96.3 \times 1.1}{3.14 \times 13.3^2} = 0.19 \text{ in./hr.}$$

and for a 24 hour set

Av. depth = 0.19 in./hr. x 24 hrs. = 4.6 in.

The E_a can be computed (assuming negligible overlap and drip which could cause some water to go too deep) by

$$E_a = \frac{3.3}{4.6} \times 100 = 72\%$$

Analysis and recommendations

The irrigation objectives must be known before the system operation can be intelligently evaluated. *Uniformity of application* and the *efficiency of storing* water for plant use are the two most important points to be considered. For evaluating orchards' sprinkler systems, uniformity and efficiency must be qualified, since it is not practical to have complete coverage in many situations. Fortunately with mature trees having extensive root systems the extraction occurs wherever there is soil moisture. Therefore, any stored water may be absorbed by the roots.

The uniformity of irrigation may be evaluated by the Distribution Characteristic, DC. Since only part of the area is left dry, the smaller wetted area should be irrigated proportionally more often to supply the total water needed for evapo-transpiration. For example, if only half of the area is wetted, the irrigation frequency must be doubled. (See Intentional Under-Irrigation in the Introduction section).

The most important objective of the field evaluation is to determine how effectively the water is being applied. Since orchard irrigation almost always leaves some areas and depths under-irrigated but still results in a very satisfactory irrigation program, the term Application storage Efficiency, E_a, was developed to replace AE.

Uniformity was good as indicated by the DC of 66%. A much higher DC value having a greater depth infiltered near the perimeter would result in a little water going too deep because of overlap, unless the effective radius of 13.3 ft. were reduced, i.e., the wetted diameter should be reduced from 26.6 ft. to nearly 24 ft. which is the tree spacing. (See Figure II-14.)

Application efficiency as represented by the E_a of 72% is a fairly low value particularly in view of the value of DC. A study to determine why the E_a is low will indicate what management steps might be taken to improve efficiency.

Unaccounted losses such as evaporation are equal to the difference between the rate applied (0.19 in./hr.) and the rate infiltered (0.17 in./hr.). This is equal to (0.19 - 0.17)/0.19 = 10% of the water applied which is too high for evaporation only. However, it is a reasonable figure, since it also includes any measurement errors. These losses cannot be controlled by management practices.

Losses by deep penetration can be identified by the differences between the average depths infiltered 0.17 in./hr. x 24 hrs. = 4.1 in. and stored 3.3 in. This (4.1 - 3.3) / 4.6 = 18% of the applied water, which goes too deep, is a large amount for a partial area irrigation program. By observing the depth profile and the 4.0 in. smd line on Figure II-15, it can be seen that there is appreciable deep percolation in the central portion of the pattern even though it is nearly uniform. A depth of 5.0 in. infiltrates near the sprinkler while only 4.0 in. can be stored. This excess depth occured because the 24-hour set time is too long.

Improvements. A major area for improvement would be the reduction of deep percolation losses. This could be accomplished by:

1. Reducing the time of irrigation to less than 24 hours.

2. Reducing the frequency by a day or two, other conditions except duration remaining the same.

3. In addition, try reducing the pressure to reduce the flow rate so that the 24-hour duration could be continued. The results would need to be re-evaluated to see if they were satisfactory. The pattern could become even better than before, as will be shown.

Time of irrigation, T_i, which is how long irrigation should be run to replace the smd, can be found by trial. Noting in Figure II-15 that 5.0 in. is representative of the maximum infiltered depth for a 24-hour set and smd is only equal to 4.0 in., T_i can be estimated from

$$T_i = \frac{4.0}{5.0} \times 24 = 19 \text{ hrs.}$$

Using instead of the original 24-hour set duration, a new value of E_a similar to Figure II-15 can be determined. This will require plotting a new depth infiltered profile and proceeding with the evaluation outlined earlier to obtain

$$E_a = \frac{3.2}{3.6} \times 100 = 89\%$$

The figures showed the unaccounted losses remained at about 10%, but the losses to deep percolation were reduced to only 1%. The average depth stored in the wetted area was reduced from the initial 3.3 in. to 3.2 in., because less of the area received the full smd of 4.0 in. This will require reducing the irrigation interval to 3.2/3.3 = 97% of the initial interval; however, the application time will be reduced to 19/24 = 79% of the original.

Average depth applied. The ratio of wetted area to actual tree area must be determined before the average depth of water (or volume) to be applied to a field and the probably frequency of irrigation, based on anticipated evapo-transpiration rates, can be computed. The wetted area provided for each tree is

$$A_w = \pi r^2 = 3.14 \times 13.3^2 = 556 \text{ sq. ft.}$$

and the area occupied by each tree on a 24 ft. by 24 ft. is

$$A_t = 24 \times 24 = 576 \text{ sq. ft.}$$

Evapo-transpiration and water applied are computed on a field basis assuming the entire soil area is functioning. Therefore, for the 24-hour set where the average depth stored in the actual wetted are is 3.3 in. the average depth of water stored over the whole field is

$$D_{av} = \frac{556}{576} \times 3.3 = 3.2 \text{ in.}$$

Alternate side irrigation is generally a good management practice. It is an especially good when the portion of the total area wet is small, since it provides additional safety by reducing the average crop stress between irrigations.

Summary

The analysis of the field measurements provided information about the sprinkler and its operation. The DC of 66% indicated the pattern was uniform with a fairly rapid drop off in application rate at the outer perimeter. A little higher value and steeper drop off would be even better, since there was only a small overlap at the operating radius of 13.3 ft. with 24 ft. tree and sprinkler spacing. The current irrigation management program of 24-hour sets produced an E_a of 72%. This is quite low for orchard sprinklers, since 28% of the applied water would not be available for the trees. Of this approximately 10% was lost to evaporation and/or possible inaccuracies. (Leakage from the sprinkler was not measured and is not included in the 10%). The remaining 18% went too deep. This deep percolation loss was caused by running the sprinkler 24 hours which was too long. The study showed that 19 hour sets would improve the E_a to 89%.

For the smd of 4.0 in., an average of about 3.3 in. was stored in the wetted area by the 24-hour set, but only 3.2 in. would be stored with a 19 hour set. Changing to a 19-hour set would require slightly more frequent (3%) irrigation but only require 79% as much water per irrigation.

For this non-overlapping pattern, which only wets part of the soil, The average depth of 3.2 in. stored over the entire area should be used for irrigation frequency computations based on the evapo-transpiration rate. For determining the deficiency at which to irrigate from field soil moisture deficiency checks, the smd should be matched to a MAD in the central, uniformly irrigated area. Since at the time of this field study, smd = MAD = 4.0 in., it was the correct day for irrigating.

Center Pivot Sprinklers

Center pivot laterals continuously move while irrigating. The inlet end of the lateral is fixed to the stationary pivot point while the other end moves in a large circle. The lateral consists of a series of spans ranging in length from 90 to 250 feet and supported above the crop by drive units (see Figure II-4). Devices are provided at each drive unit to keep the lateral in line between the pivot and end drive unit which is set to control the speed of rotation. The area irrigated by each sprinkler (with a constant sprinkler spacing) along the lateral grows progressively larger toward the moving end. Therefore, the sprinklers must be designed to have progressively greater discharges and/or closer spacings to achieve a uniform application.

The most common length of center pivot lateral is a quarter mile (1320 ft.) to irrigate the circular portion (130 ac.) of a quarter section (160 ac.). Typically, the application rate near the moving end is 1.0 in./hr. or greater. This exceeds the intake rate of most soils except for the first few minutes at the beginning of each irrigation application. To minimize surface ponding and/or runoff the laterals are usually rotated every 10 to 72 hours depending on the soil infiltration characteristics, system capacity, and MAD.

Under such high frequency irrigation, smd checks are mainly useful for evaluating deep moisture conditions. This is especially true where intentional under irrigation is practiced to utilize deep stored moisture.

The field evaluation of center pivot sprinklers involves checking the: DU along the lateral, reletive uniformity problems due to topography, infiltration and/or runoff along the outer end, crop condition, and deep moisture conditions.

Center pivot systems are propelled by utilizing some of the water or by independent power sources such as electricity, oil hydraulics, compressed air, etc. Where water is used, it must be included as part of the total applied water and usually results in some lowering of efficiencies. When the water discharging from the pistons or turbines is distributed as an integral part of the irrigation pattern, its effectiveness should be included in DU; otherwise it should be ignored in the DU computations.

There are similarities between the procedures and logic behind the evaluation of all types of sprinkler systems. To shorten this section on center pivot systems, many parts will depend on a good understanding of the procedures presented under "Full Evaluation - Fixed Grid Sprinklers."

Evaluation

The following information is required:

1. Rate of flow from water drive motors and total system.
2. Depth of water caught in the catch containers.
3. Speed of travel of end drive unit.
4. Machine length to end drive unit and additional radius irrigated.
5. Width of the wetted strip at end drive unit.
6. Pressure and size of largest sprinkler nozzles at the end of the machine.
7. Approximate elevation differences (±5 ft.) between the pivot and high and/or low points in the field (and along the line of the test position).
8. Additional data as indicated on the data form.

An accurate measurement of the flow rate into the system is needed for determining the PE of the system; however, if there is not an accurate flow metering device at the inlet, the PE can only be estimated. Under high frequency irrigation, it is difficult to evaluate the AE since the typical irrigation depth of 0.3 to 1.0 inches may be less than the provable accuracy of the smd estimate.

Equipment needed

In addition to the equipment listed for the full evaluation of fixed grid sprinkler systems the following would be useful: a hand level to check elevation differences and metering equipment for checking system capacity.

Field procedure

Fill in the data blanks of Form II-3 as the field procedure is conducted in the following stages:

1. In a field with a low growing or no crop, test the system when the lateral is in a position with a minimum of elevation differences. In tall growing crops such as corn, the system should be tested where the lateral crosses the access road to the pivot point.

2. Set out the catch containers along a radial path beginning at the pivot with a convenient spacing no wider than 30 ft. A 15 or 20 ft. spacing is preferable. The radial path does not need to be a straight line and the containers can be placed just ahead of the wetting front. A most convenient spacing can be obtained by dividing the span length by a whole number such as 4, 5, 6, etc. For example, if the span length is 90 ft. use a 30 ft., or better yet a 22.5 ft. spacing. This simplifies the catchment layout since measurements can be made from each wheel track and the spacing related to the span, i.e., 4th span + 50 ft. Obviously, containers should not be placed in the wheel tracks or where they would pick up the waste exhaust water from water drive systems (where the exhaust is not distributed). Where an attempt is made to incorporate the exhaust water into the pattern the containers should be laid out to pick up representative samples of the water.

As an example, a typical layout between wheel tracks for 90-foot spans and any type of drive might be:

a. Place the first container 5 ft. downstream from the in-board wheel track.

b. Place the next 3 containers at 22.5 ft. intervals.

c. The last container will now be 17.5 ft. from the down stream wheel track.

d. Repeat the above procedure to the end of the actual circle. It is most convenient to leave out the first few containers adjacent to the pivot. Typically, the containers under one or two spans are omitted with little adverse effect on the evaluation. A number should be assigned to each container location with a sequencial numbering system beginning at the pivot end. (Even the locations which do not have containers under the first spans should be numbered.)

3. Determine the length of time it takes the system to make a revolution. This can be done by dividing the speed of the end drive unit by the circumference of the outer wheel track.

a. Stake out a known length, say 20 ft., along the outer wheel track and determine the time required for a point on the drive unit to travel between the stakes. The speed of travel will be the distance divided by the time. (An alternate method is to determine the distance traveled in a given time, say 10 minutes.)

b. To determine the circumference, first determine the radius between the pivot and the outer wheel track. Since most machines have uniform span lengths (except for perhaps the first span), the radius can normally be determined by multiplying the span length by the number of drive units. The circumference is 6.28 times the radius.

4. Determine the irrigated area by first estimating the radius of the irrigated circle and

$$\text{Area} = \frac{3.14 \times (\text{radius ft.})^2}{43560} = \text{acres}$$

5. At the time the sprinklers reach the test area, set aside 2 containers with the anticipated catch to check the mangnitude of evaporation losses.

6. Check the presence of the sprinklers near the pivot and at the outer end. Note the nozzle size of the largest sprinklers.

7. On water driven systems number each drive unit beginning with the one next to the pivot. Time how long it takes to fill the bucket (or jug) of known volume with the discharge from the water motor in the outer drive unit. The exact method for doing this depends on the water motor set up and it may require a short section of hose.

An estimate of the sum of the flow rates from all of the drive motors is

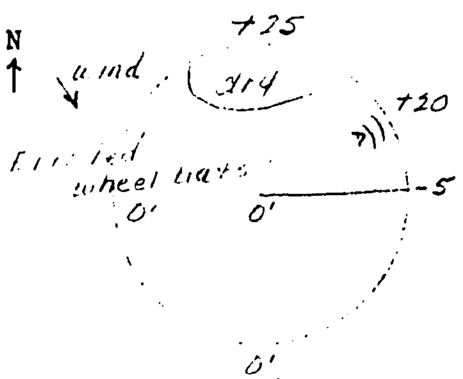
$$\text{Total drive flow} = \frac{\text{sum of drive unit numbers x flow from end unit}}{\text{Number of drive units}}$$

8. If the system is equipped with a flow meter, measure the rate of flow into the system. Most standard flow meters only indicate the total volume of water which has passed. To determine the flow rate read the meter at the beginning and end of a 10-minute period and calculate the rate per minute. To convert from cubic feet per second (or acre-inches per hour) to gpm multiply by 453.

9. Fill in the blanks in Form II-3a, dealing with climatic conditions, machine and test specifications, topography and general system and crop performance.

FORM II-3a. CENTER PIVOT EVALUATION DATA SHEET

1. Location *Field F202*, Observer *JK*, Date & Time *8/18/[illegible]*
2. Equipment make *HB 120*, length *1375* ft., Diameter *6 5/8* in.
   type of drive *water*, is drive water distributed? *yes*
3. Discharge from end drive motor *5.0* gal per *.37* min = *13.5* gpm

   Total drive flow = (sum of drive unit numbers *120* x *13.5* gpm from end) / (number of drive units *15*) = *107* gpm
4. Speed of end drive unit *45* ft. per *10* min = *4.5* ft./min.
5. Time per revolution = (End wheel truck radius *1350* ft.) / (Speed *4.5* ft./min. x 9.55) = *31.4* hr.
6. Application time at end = (water pattern width *174* ft.) / (speed *4.5* ft./min.) = *[illegible]* min.
7. Irrigated area = (wetted radius *1462* ft.)^2 x 3.14 / 43560 = *152* acres
8. smd near pivot *0* in.
   at 3/4 point *0* in.
   at end *2.0* in.
9. Surface runoff conditions
   at 3/4 point *slight*
   at end *moderate*
10. Crop and condition: *corn, good except on north edge*
11. 

   * Mark position of lateral, elevation differences, wet (or dry) spots and wind direction on circle.

   Wind *12* mph, Temperature *70* °

   Pressure at pivot *26* psi

   Pressure at end nozzle *60* psi

   Diameter of largest nozzle *1/2* in.

   Comments: *[illegible] ... but end part circle sprinklers seemed out of [illegible]*
12. System flow *11500* gal. per *10* min = *1150* GPM
13. Average weighted catches: catch container factor *250* ml/in.

   System average = (Sum of weighted volumes *257,708*) / (Sum of position numbers *2044*) = *126* ml or *.50* in.

   Low 1/4 = (Sum low 1/4 weighted volumes *57,974*) / (Sum position numbers low 1/4 *518*) = *112* ml or *.45* in.
14. Estimated gross in./rev. and minimum daily application:

   Av. system catch *126* ml

   Evaporation loss *4* ml

   Gross application *130* ml or *0.52* in.

   Min. daily = (24 x low 1/4 *.45* in.) / (*31.4* hrs. per revolution) = *0.34* in./day

FORM II-3b CENTER PIVOT EVALUATION DATA SHEET

1. Location Field 202, Observer JK, Date & Time 7/18/71 11 a.m.

2. Span length 90 ft, container spacing 22.5 ft. container 250 ml/in.

3. Evaporation loss: Container #1 / Container #2

	Container #1	Container #2	
Initial volume	150 ml	150 ml	
Final volume	- 147 ml	- 145 ml	
Loss	3 ml	5 ml	av. 4 ml

4.

Span No.	Catch Container Position Number	X Volume ml	= Weighted Volume	Span No.	Catch Container Position Number	X Volume ml	= Weighted Volume
Start numbering at pivot end of first span although first few container positions will be blanks				10	37	118	4366
				10	38	127	4826
				10	39	115	4485
				10	40	147	5880
	5	—		11	41	127	5207
	6	—		11	42	122	5124
	7	—		11	43	118	5074
	8	—		11	44	144	6336
	9	141	1269	12	45	112	5040
	10	160	1600	12	46	124	5704
	11	122	1342	12	47	126	5922
	12	130	1560	12	48	151	7097
	13	143	1859	13	49	120	5880
	14	150	2100	13	50	122	6100
	15	134	2010	13	51	115	5865
	16	123	1968	13	52	143	7436
	17	144	2448	14	53	124	6572
	18	138	2484	14	54	144	7776
	19	135	2565	14	55	115	6325
	20	207	4140	14	56	160	8960
	21	122	2562	15	57	120	6840
	22	114	2508	15	58	110	6380
	23	115	2645	15	59	109	6431
	24	138	3312	15	60	117	7020
	25	109	2725	16	61	95	5795
	26	113	2938	16	62	194	12028
	27	114	3078	16	63	148	9324
	28	128	3584	End	64	82	5248
	29	116	3364		65	~~72~~	omit
	30	107	3210		66		
	31	122	3782		67		
	32	140	4480		68		
	33	117	3861		69		
	34	105	3570		70		
	35	111	3885		71		
	36	125	44[illegible]		72		

5. SUMS of:

Catch Position Numbers used	2044
Weighted Volumes all containers	257,708
Weighted Volumes low 1/4	57,974
Catch position numbers low 1/4	518

10. Estimate the width of the wetted pattern (perpendicular to the lateral) and the duration of time water is received by the containers near the end drive unit.

11. Measure the depth of water in all the containers as soon as possible and observe if they are still upright noting abnormally low or high catches. The best accuracy can be achieved by using a graduated cylinder to obtain volumetric measurements. These can be converted to depths if the area of the container opening is known. For quart oil cans, 200 ml corresponds to 1.0 in. depth. Measure the catch of one of the evaporation check containers about mid way during the catch reading period and the other one at the end.

Utilization of field data

The volumes caught in the containers must be weighted, since the catch points represent larger and larger areas as the distance from the pivot increases. To weight the catches according to the distance to the pivot, each catch value must be multiplied by a factor related to the distance to the pivot. This weighting operation is simplified by using the container layout procedure described earlier and Form II-3b.

The average weighted system catch is found by dividing the sum of the weighted catches by the sum of the catch position numbers. Space for this computation is provided on Form II-3a part 13 and Form II-3b part 5.

For the average minimum weighted catch, an unknown number of containers which represents the low 1/4 of the irrigated area must be used. Selecting the low 1/4 is accomplished by picking progressively larger catches and keeping a running total of the associated position numbers until the sub-total approximates 1/4 of the sum of all the catch position numbers. The average weighted low 1/4 of the catch is then found by dividng the sum of the low 1/4 of the weighted catches by the sum of the associated catch position numbers. Space for this computation is provided on Form II-3a part 13 and Form II-3b part 5.

Distribution Uniformity, DU

In order to determine if the system is operating at an acceptable and economical efficiency, the deep percolation losses and uniformity should be evaluated by calculating the DU which is

$$DU = \frac{\text{average weighted low 1/4 catch}}{\text{average weighted system catch}} \times 100$$

which for the example problem is

$$DU = \frac{112 \text{ ml}}{126 \text{ ml}} \times 100 = 89\%$$

This is a reasonable value and is independent of the speed of revolution. If the DU is low it is useful to make a plot of the volume of catch versus distance from the pivot as shown in Figure II-16. Such a plot is useful for spotting the problem areas and locating improperly nozzled or mal-functioning sprinklers. There are often high points near each water driven wheel unit where the water is distributed as part of the pattern.

If the system is operating on an undulating or sloping field and is not equippped with pressure or flow regulators, the DU will vary with the lateral position. The DU will remain nearly constant if the elevation differences in feet divided by 2.3 (to convert to an equivalent psi) do not exceed 20% of the end sprinkler pressure. Thus for the example test the DU would be little affected by line position since the end sprinkler pressure was 60 psi and the maximum elevation differences were only 25 ft. (which is equivalent to 11 psi).

Potential irrigation system Efficiency, PE

If the pivot point is equipped with an accurate flow measuring device, the PE can be determined by

$$PE = \frac{\text{minimum rate caught}}{\text{average rate applied}} \times 100$$

The minimum rate caught is the average weighted low 1/4 catch expressed as a depth per revolution. The average rate applied per revolution is calculated from the hours per revolution, system flow in GPM and the wetted area is acres by

$$\text{Average rate applied} = \frac{\text{Hrs. x GPM}}{\text{453 x Acres}} = \text{in./rev .}$$

From the data computed on Form II-3a in parts 5, 7, 12, and 13 the computations are

$$\text{Average rate applied} = \frac{31.4 \times 1150}{453 \times 152} = 0.525 \text{ in./rev.}$$

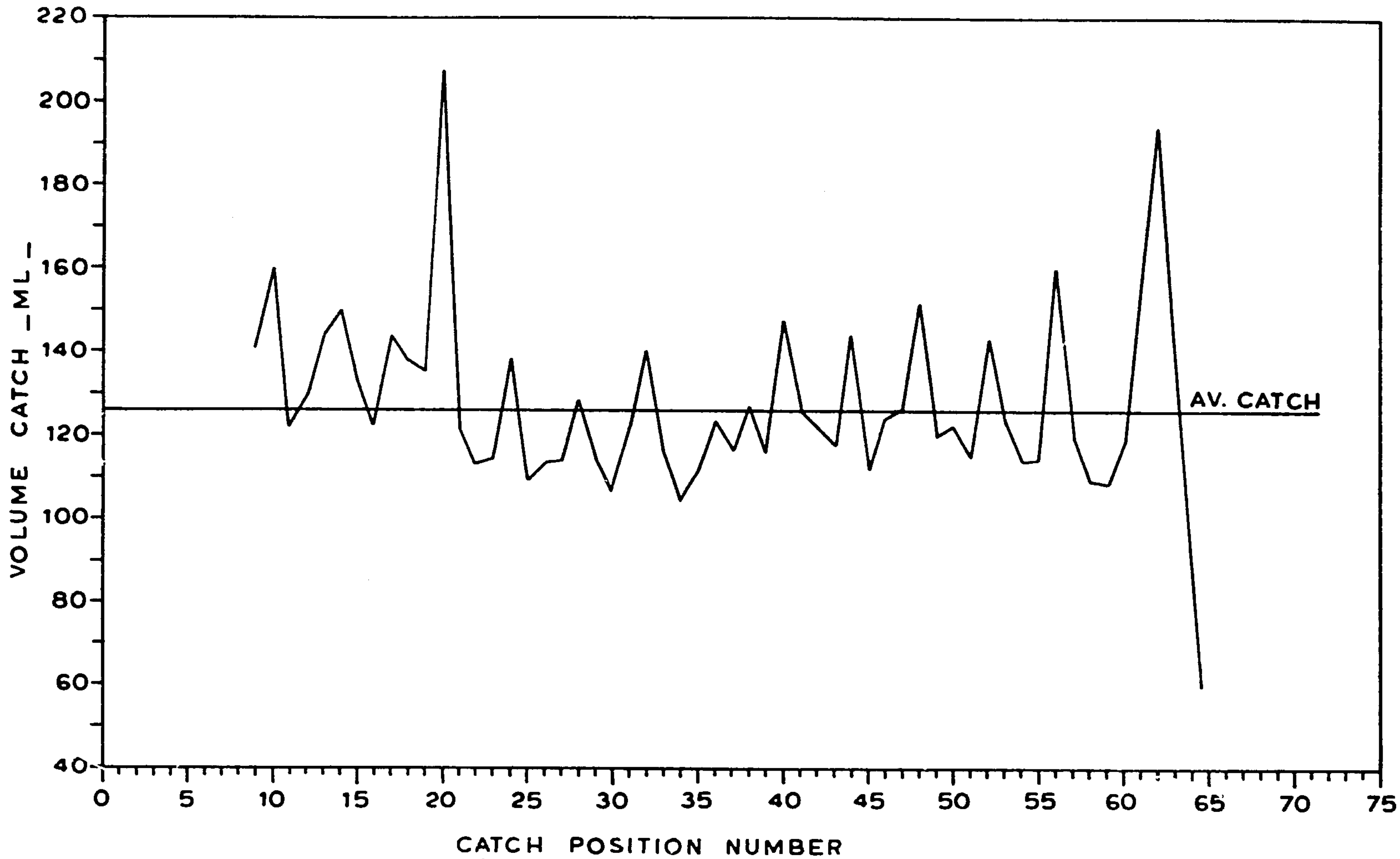


Figure II-16. Container catch profile from center pivot sprinkler evaluation test.

and

$$PE = \frac{0.45}{0.525} \times 100 = 86\%$$

The system flow rate and PE can be estimated without a flow meter at the inlet. This is done by first estimating the gross application, in/rev., as in Form II-3a part 14 and then estimating the distributed flow in GPM by

$$\text{Distributed flow} = \frac{453 \text{ acres x gross in./rev.}}{\text{Hrs./rev.}} = \text{GPM}$$

If there is drive motor water which is not distributed it must be added to the distributed flow to obtain the estimated system flow.

The PE is then computed as before using the estimated system flow.

The above computations of PE are only meaningful if there is little or no runoff. As mentioned earlier, runoff and/or ponding is apt to occur near the moving end of the system. If runoff is occuring (See Figure II-17) increasing the system speed will reduce the depth per application and often eliminate runoff. Other methods for reducing runoff include the following:

1. Using an implement called a *pitter* which scrpaes identations in the furrows followed by small dikes every 2 or 3 ft.

2. Reducing the total depth of water applied per week by turning the system off for a period after each revolution. (Automatic *stop in slot* devices are available for many systems.) This will allow the surface soil to become drier between irrigations and thus have a higher infiltration capacity. Careful planning is required in order not to under irrigated so much that crop yields are affected (See Chapter I, "Intentional Under-Irrigation").

3. Decreasing nozzle sizes to decrease the sytem capacity and application rate. The nozzles must all be changed to maintain uniformity

4. Increasing system pressure and reducing nozzle size (throughout the system) to maintain the same system flow rate but improve drop size breakup.

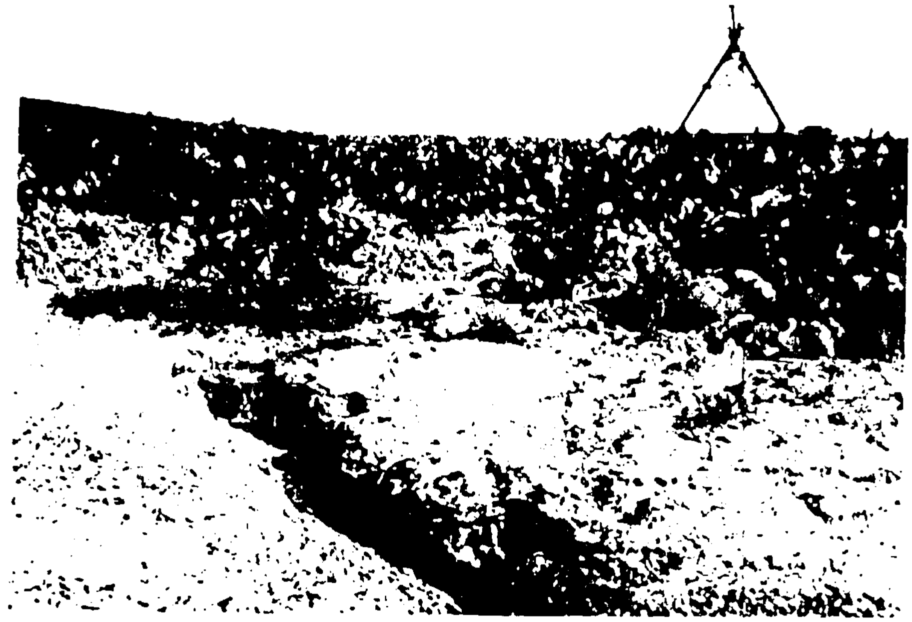


Figure II-17. Runoff at the outer end of a center pivot.

Actual application storage Efficiency, AE

The depth of water applied per revolution is usually less than the normal inaccuracy of measuring the smd. Therefore, it is impractical to try to compute AE.

Checks of the smd in several places, especially in the vacinity of the outer end, are useful for spotting accumulated deep moisture deficits. Deficits can occur due to overall under irrigation, a low DU, or a low PE due to runoff. Deficits due to runoff are most apt to occur at high spots in the outer fifth of the circle.

Application rates

The maximum application rate in the vacinity of the moving end is normally quite high. It can be estimated from the average depth applied per revolution and the time water is being applied at the end (or opportunity time) by

$$\text{Max. Application rate} = \frac{90 \times \text{inches depth}}{\text{minutes time}} = \text{in./hr.}$$

which for Form II-3a parts 6 and 13 is

$$\text{Max. application rate} = \frac{90 \times 0.50}{39} = 1.2 \text{ in./hr.}$$

Since the opportunity time increases toward the pivot end, the application rate decreases toward the center of the circle.

Analysis and recommendations

A number of observations and some recommendations can be made from the additional data on Form II-3 and the DU and PE computations.

The pressure at the large end nozzle was too low for good jet breakup (1/2 in. at 60 psi). This resulted in large droplets which tended to seal the soil surface and decrease the infiltration capcity. For good breakup from regular nozzles the largest nozzles for given pressures should be: for 55 psi up to 1/4 inch: for 65 psi up to 3/8 inch: for 75 psi up to 1/2 inch;and for 85 psi up to 3/4 inch. What breakup pins or orifice type nozzles are used pressures can be reduced by 20%.

The time per revolution which was estimated to be 31.4 hr. (See Form II-3a part 5) should be checked against the actual time required. (Quite often the operator will be able to give a good estimate of the actual time.) The uniformity of the turn speed, which is essential to efficient watering, can be evaluated by a comparison of the computed and actual time per revolution. Speed checks where the lateral is traveling up and down steep slopes may also be useful.

Run-off. Some runoff was observed near the outer end of the system where the application rate reaches 1.2 in./hr. This reduces the PE of 86% by an unknwon amount. Further evidence of the runoff was noticed in the outer wheel tracks which were erroded 2 ft. deep in steep areas of the field. Runoff water tends to travel down the furrows and collect in the wheel tracks. This coupled with the digging actions of the wheels can results in such excessively deep errosion that the drive units high center (the span structure scrapes the ground and the system stops.) Other evidences of runoff are the dry looking corn crop along the north edge of the field which is on a hill and the deep moisture deficit indicated by the smd of 2.0 in. all around the outer edge of the circle. (See Form II-3a parts 8, 9, 10 and 11.)

Methods for decreasing the runoff were described earlier. Of these methods, reducing nozzle sizes (and increasing pressures) would probably produce the best results; however, increasing the machine speed to approximately one revolution every 24 hours and stopping the system for about 8 hours after each revolution would be a simple solution. (The duration of time between revolutions should always be a couple of hours more or less than 24, 48, 72, etc.) This is done so the lateral will continuously change positions relative to the normal daily wind cycles.

Over-Irrigation. With high frequency irrigation, the smd is always near zero and it is difficult to measure over-irrigation. However, for the operation evaluated, the estimated water required for corn in that area was only about 0.25 in./day. Since the operator was running the system almost continously and applying a minimum application of 0.34 in./day (see Form II-3a part 14) he was obviously over irrigating. If he would shut off the irrigation for 8 hours after every 24 hours, as suggested for reducing runoff, the minimum application would be (24/32) x 0.34 = 0.25 in./day.

Improvements. The operational changes mentioned above will not only improve the irrigation efficiency but also reduce the operating problems associated with errosion in the wheel tracks. Under the current management the lateral often gets out of line and shuts off in the erroded areas. The operation must then pull the system in line and fill in the erroded tracks.

From Figure II-16 it is apparent that a sprinkler in the vacinity of catch position number 20 is either stuck or has too large a nozzle. Also the ragged pattern near the end indicates the part circle sprinklers on the end are improperly designed and/or set with the wrong arc. The sprinklers in these two areas should be checked and replaced or adjusted as needed.

When there are no runoff problems and the system capcity is not sufficient to meet the crop water requirements, slowing the system will usually improve yields. By slowing the system, deeper but less frequent irrigations are applied. This reduces direct evaporation losses and improves crop water use efficiency.

Summary

The DU = 89% and calculated PE = 86% of the system are very good. The main system problems are associated with runoff and over-irrigation.

Several suggestions for reducing runoff were given. These included: reducing the system flow and increasing inlet pressures; changing the speed of rotation; and periodically turning the system off to reduce the total water applied.

Traveling Sprinklers

The most common type of traveler used in agriculture is a giant 500-gpm sprinkler which has a wetted diameter of over 400 ft. and is mounted on a moving vehicle. The vehicle is equipped with a water piston or turbine powered winch which reels in a cable. The cable guides the unit down a path as it tows a high-pressure flexible hose. The hose is connected to the water supply pressure system. (See Figures II-5 and 18). The most typical hose has a 4-inch diameter and is 660-foot long which allows the unit to travel 1320 ft. between set-ups.

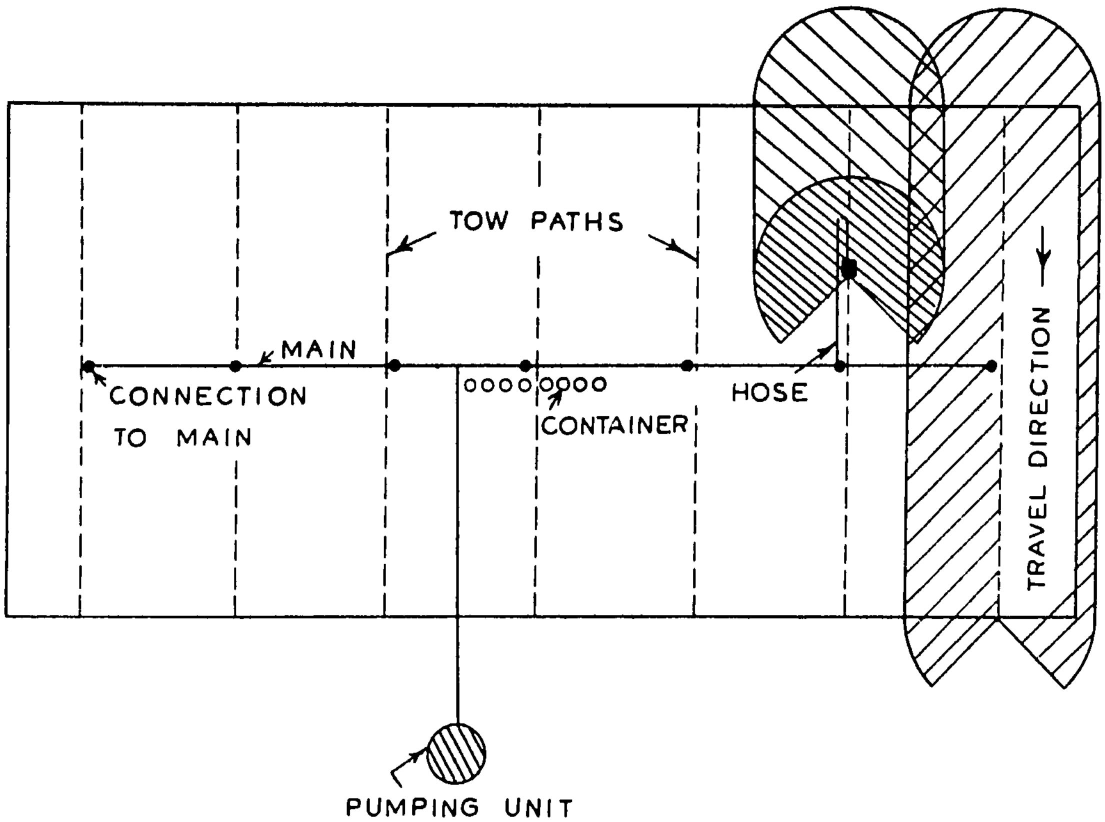


Figure II-18. Typical traveler sprinkler layout.

As the traveler moves along its path the sprinkler wets a strip of land rather than a circular area as shown in Figure II-18. After the unit reaches the end of a travel path it is moved and set up to cover an adjacent strip of land. The amount of overlap between adjacent strips depends on the distance between travel paths and the diameter wetted by the sprinkler. Frequently a part circle sprinkler is used with the dry part of the pattern positioned over the travel path so the unit can travel on dry ground.

The procedures which follow are mainly designed to check the uniformity and efficiency of irrigation across the travel paths. However, due to the nature of the operation and the largeness of the sprinklers, the quality of irrigation around the field boundaries will be quite low. It is particularly difficult to obtain high quality irrigation at the ends of the tow paths and on small fields this represents an appreciable area (up to 200 feet on each end).

If the unit is powered by a water piston, the expelled water should not be included in the uniformity but should be included in the efficiency computations.

There are many parts of the procedures and evaluations of travelers which are closely related to those used for the fixed grid and center pivot sprinkler systems. A general knowledge of the evoluation techniques presented for the fixed grid and center pivot systems will be assumed.

Evaluation

The following information is required:

1. Nozzle size and type for estimating the system flow rate.
2. Pressure at the nozzle.
3. Depth of water caught in catch containers.
4. Speed of travel when the unit is at the upper and lower end of the tow path.
5. Spacing of the tow paths.
6. Water piston discharge (if piston powered).
7. Additional data as indicated on Form II-4.

An accurate estimate of the flow rate from the nozzle is necessary for calculating the PE and AE of the system. A good way to obtain an estimate of the flow is from a sprinkler performance chart which should be available from the manufacturer.

Equipment needed

In addition to the equipment listed for the full evaluation of fixed grid sprinklers is a hand level which is useful to check field elevations. The pressure guage should read up to 150 psi. If the traveler is not powered by a water piston, the bucket and hose are not needed.

Field procedure

1. Choose a test location about midway in the tow path the traveler will be operating in. The location should be far enough ahead of the sprinkler so no water is reaching the test area prior to completing the catch container set up. It should also be far enough from the lower end of the path so the back (or trailing) edge of the sprinkler pattern passes completely over it (before the sprinkler reaches the end).

A good location for the test area is along the mainline where an access road is often provided. In tall growing crops such as corn, an access road is the only practical location for the test.

2. Check the soil moisture dificiency, smd, at the following locations: close to the tow path; one-fourth of the distance to the next tow path; and mid-way between the tow path in use and the next one to be used.

3. Set out a row of catch containers across the tow path with a spacing of 10 ft. (See Figure II-18). The containers which are adjacent to (or in) the tow path should be set 5 ft. to either side of the center of the path. The outer containers should be at the edges of the wetted strip. (It is a good practice to provide a couple of extra containers on both ends of the container row to allow for wind changes.)

4. Determine the travel speed of the unit as it passes over the row of containers. The speed should also be checked at the upper and lower ends of the tow path.

Stake out a known length, say 10 ft., and determine the time required for a point on the vehicles to travel between the stakes. (An alternate method is to determine the distance traveled in a given time, say 10 minutes.)

5. Measure the spacing between tow paths.

6. Set out two containers with the anticipated catch to check the magnitude of evaporation losses. The first containers should be set out when the wetted pattern first reaches the catch row and the second containers when the sprinkler (vehicle) reaches the row.

7. Check the pressure at the sprinkler nozzle when it is about directly over the catch row. Also note the sprinkler make, model, type of nozzle (orifice ring or taper bore), and nozzle size. (It is a good practice to also measure the nozzle size when the system is turned off to check for errosion so the flow rate estimate can be adjusted if necessary.)

8. Estimate the sprinkler discharge from the performance chart (available from the distributer or manufacturer). A typical performance chart will give the sprinkler discharge and diameter of coverage for various nozzle sizes at different pressures.

9. In water-piston powered travelers, time how long it takes to fill the bucket (or jug) of known volume with the discharge from the piston.

10. Check the hose inlet pressure and the inlet pressure at the traveler, if feasible.

11. Fill in the blanks in Form II-4 dealing with climatic conditions, machine and test specifications, topography, and general system and crop performance.

12. Measure the depth of water in all the containers as soon as possible and observe if they are still upright noting abnormally low or high catches. Then measure the catch in the two evaporation check containers.

Form II-4 is laid out to simplify the procedure of overlapping the catches to simulate a complete irrigation between adjacent tow paths. To use the form, number the containers from the tow path outward beginning with 1,2,3, etc., to the right and to the left (looking upstream). Enter the container numbers (and catch values) on Form II-4 as follows: for the left side data start numbering with container 1 opposite the tow path width of 10 ft. and number downward; and for the right side data start the numbering with container 1 opposite the actual tow path width (which for the example field evaluation is 330 ft.) and number upward.

Utilization of field data

Assuming the test is representative and the next run would give identical results, the right hand side of the catch pattern may be overlapped on the left side (See Figure II-18). Form II-4 is laid out to simplify this operation.

The overlapped data is an estimate of the profile of the depth of irrigation water between adjacent tow paths. For the computations of DU, PE, and AE which follow, it will be assumed that this depth profile is representative of the distribution throughout the field. In other words, the assumption is that the depth profile across the strip between two paths is the same from the upper to the lower end of the strip. This is obviously subject to question because of: discontinuities at the path ends; changes in travel speeds; pressure variations due to elevations, and wind changes.

Distribution Uniformity, DU

In order to determine if the system is operating at an acceptable and economical efficiency, the deep percolation losses and uniformity should be evaluated by calculating the DU which is

$$DU = \frac{\text{average low 1/4 catch}}{\text{average system catch}} \times 100$$

which for the sample test (See Form II-4 part 11.)

$$DU = \frac{322\ \text{ml}}{455\ \text{ml}} \times 100 = 71\%$$

or

$$DU = \frac{1.61\ \text{in.}}{2.27\ \text{in.}} \times 100 = 71\%$$

This is a fair value for a traveler system and is generally independent of the speed of travel.

It is useful to make a plot of the depth of catch versus distance between tow paths as shown in Figure II-19. The plot is useful for spotting the problem areas. From Figure II-19 it is apparent that either the tow paths are too far apart, which results in a low depth midway between tow paths, or the angle of the part circle is set too narrow. (The effect of decreasing the tow path spacing can be evaluated as described in the full evaluation of grid sprinklers.) Widening the angle would reduce the depth applied near the paths and increase the depth in the middle.

FORM II-4. TRAVELER SPRINKLER EVALUATION DATA SHEET

1. Location *Field 200*, Observer *JK*, Date *7/5/[illegible]*

   Crop *corn*, Soil *F.S.L.*, and condition *good*

2. Sprinkler Make *Nelson*, and model *200 part circle*

   Nozzle size (actual) *1½* in., Type *Ring*, and pressure *100* psi

   Nozzle flow rate from manufacturers chart *500* GPM

3. Catch container factor *200* ml/in.

Path width feet	Left Side (containers located to the left - start at top and number down) No.	Left Side ml	Right Side (containers located to the right of path - start at path spacing and number up) No.	Right Side ml	Total ml	Total in.
10	1	560			560	2.80
20	2	540			540	2.70
30	3	510			510	2.55
40	4	490			490	2.45
50	5	505			505	2.53
60	6	475			475	2.38
70	7	480			480	2.40
80	8	460			460	2.30
90	9	430			430	2.15
100	10	410			410	2.05
110	11	370			370	1.85
120	12	325	22		325	1.63
130	13	305	21		305	1.53
140	14	345	20		345	1.73
150	15	335	19		335	1.68
160	16	310	18		310	1.55
170	17	305	17		305	1.53
180	18	290	16	35	325	1.62
190	19	250	15	75	325	1.62
200	20	230	14	120	350	1.75
210	21	215	13	215	430	2.15
220	22	165	12	365	530	2.65
230	23	95	11	410	505	2.52
240	24	65	10	515	580	2.90
250	25	25	9	540	565	2.82
260	26	–	8	525	525	2.62
270			7	500	500	2.50
[illegible]			6	490	490	2.45
[illegible]			5	470	470	2.35
[illegible]			4	490	490	2.45
310			3	540	540	2.70
[illegible]			2	605	605	3.02
[illegible]			1	625	625	3.12
[illegible]						74.87
[illegible]						
[illegible]						
[illegible]						
380						
390						

4. Type of drive *turbine*

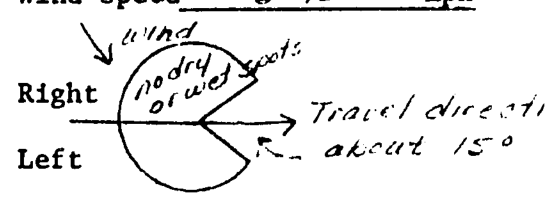
   Discharge from piston – gal/ – min. = – gpm

5. Machine inlet pressure *110* psi

   Hose inlet pressure *137* psi

6. Traveler speed
   a. at test side
   10.0 ft./*10* min. = *1.00* ft./min.
   b. at upper end
   7.5 ft./*10* min. = *.75* ft./min.
   c. at lower end
   10.2 ft./*10* min. = *1.02* ft./min.

7. Wind speed *5-10* mph



   path length *1320* ft.

8. Note part circle operation and wet (or dry) areas on the above sketch. Topography of path, High *+10*, Low *−5*

9. smd near tow path *2.1* in.
   at 1/4 - point *2.2* in.
   at mid-point *3.7* in.

10. Evaporation loss

	Container #1	Container #2
Initial	*500* ml	*500* ml
Final	*470* ml	*482* ml
Loss	*30* ml	*18* ml

   Average *24* ml *.10* in.

11. Average catches
   Total *74.87* in/ *33* = *[illegible]* in.
   Low 1/4 catch
   12.91 in/ *8* = *1.61* in.

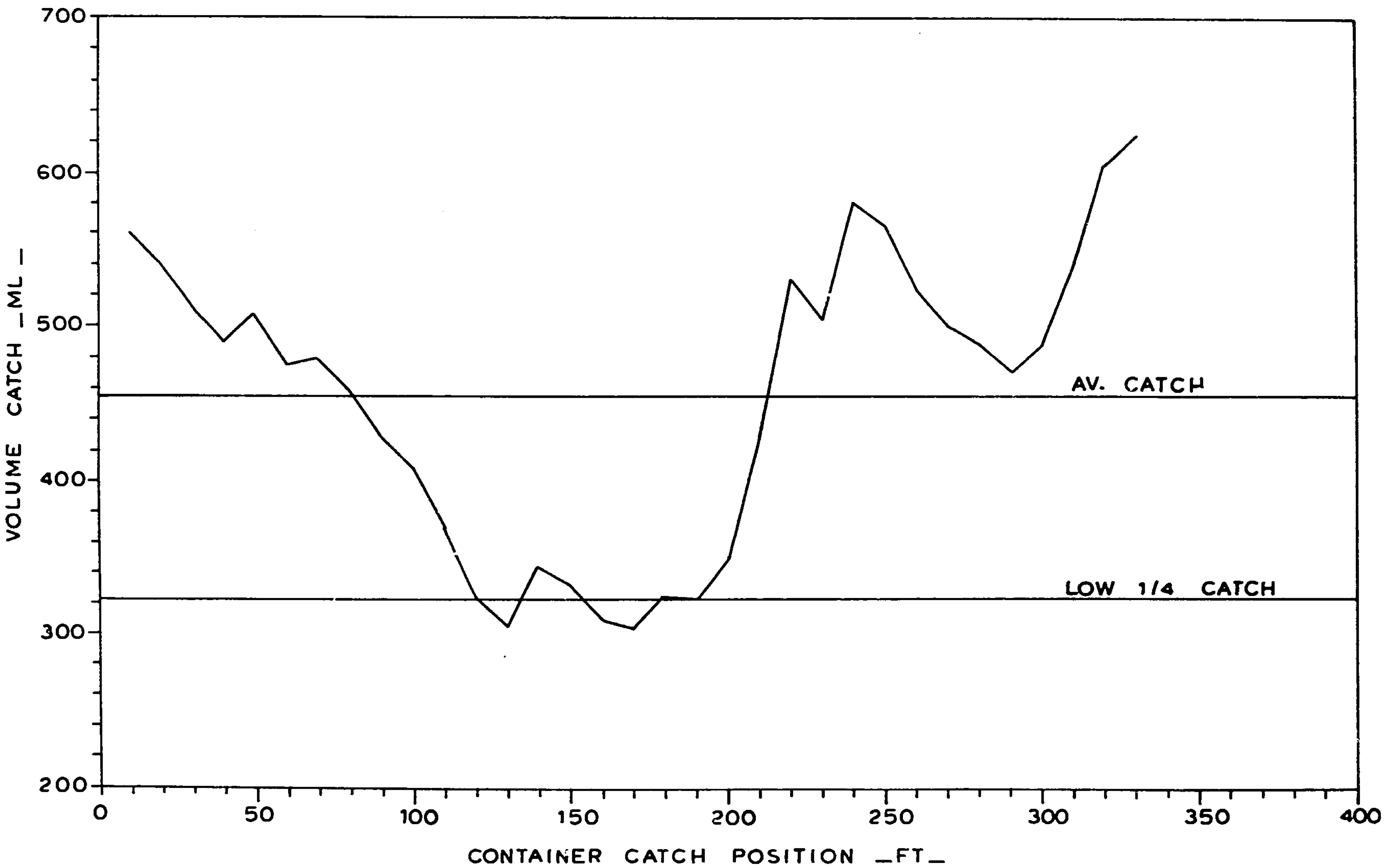


Figure II-19. Container catch profile from traveler sprinkler evaluation test.

The travel speed check (See Form II-4 part 6) shows that the unit moves faster toward the end of the travel run. The change in speed is caused by the interaction of the buildup of cable on the winch reel and the increased drag exerted by the hose as the unit moves from the upper to the lower end of the tow path. Fortunately, these two factors tend to offset each other and in the example evaluation the unit was only traveling 2% faster at the lower end than in the test area (and 5% slower at the upper end). These speed changes would lower the DU over the entire strip by about one quarter of the total percent speed change, i.e., (2 + 5)/4 or about 2%.

Since the nozzle pressure is normally in the vacinity of 100 psi, elevation differentials are usually not great enough to appreciably effect DU. Only elevation differences along the tow paths are of concern since values can be used to adjust hose inlet pressures. Assuming a 20% allowable pressure differential, the tow path elevation may vary from 40 to 50 ft without seriously affecting DU.

Changes in wind speed and/or direction can potentially greatly affect DU. This is especially true if the wind direction is appreciably different during the operation in adjacent tow paths. (Blows from the left in Figure II-18 one day and from the right the next day.) However, if the system is managed to operate approximately 24 hours in each tow path, like the example test, wind problems will be minimized. The traveler will be in about the same relative position along adjacent tow paths at a given time of day (when winds are most apt to be similar).

<u>Potential irrigation system Efficiency, PE</u>

The PE should be determined to evaluate how effectively the system can utilize the water supply and what the losses may be. Then the total amount of water required to irrigate the field can be estimated. The PE is calculated from depths (rather than rates as used earlier) by

$$PE = \frac{\text{minimum depth caught}}{\text{average depth applied}} \times 100$$

The minimum depth caught is the average of the low 1/4 catch. The average depth applied is calculated from the sprinkler discharge in GPM (plus the piston discharge in gpm if water piston driven), the tow path spacing in feet, and the travel speed in feet per minute by

$$\text{Average depth applied} = \frac{1.605 \times \text{GPM}}{\text{ft.} \times \text{ft./min.}} = \text{inches}$$

From the data given and computed on Form II-4 in parts 2, 3 and 5

$$\text{Average depth applied} = \frac{1.605 \times 500}{330 \times 1.00} = 2.43 \text{ inches}$$

and with the minimum depth of 1.61 inches

$$\text{PE} = \frac{1.61}{2.43} \times 100 = 66\%$$

Actual application storage Efficiency, AE

The effectivenss of the use of the system can be estimated by how much of the applied water is stored in the soil and available for consumption use. The AE is caluclated by

$$\text{AE} = \frac{\text{min. depth stored in the root zone}}{\text{average depth applied}} \times 100$$

It was determined that the soils hold about 1.75 in./ft. of available moisture. The root zone depth of the corn was 4.0 feet at that time and a 30% Management Allowed Deficiency, MAD, was considered ideal. This gives a MAD of 2.1 in. From the field checks of the soil moisture deficiency, smd. (See Form II-4 part 9) the smd near the tow path and at the 1/4 point was 2.1 inches and 2.2 inches respectively while in the middle of the strip smd was 3.7 inches.

The minimum depth of 1.6 inches applied occurred in the middle of the strip where the smd is 3.7 inches (see Figure II-19). Thus the system did not apply a full irrigation and there is no water loss to deep percolation in the minimum application area; therefore,

$$\text{AE} = \text{PE} = 66\%$$

It appears that much of the area is receiving adequate irrigation since the smd (and MAD) over much of the strip is less than or equal to the depth of application. However, under-irrigation has created a cumulative deficit in the middle area.

Application rate

The giant sprinklers which are normally used on travelers produce a rather flat pattern of distribution. That is, if the traveler vehicle were standing still, the depth of application or application rate over most of the area would be fairly uniform. An estimate of the application rate can be obtained from the flow in GPM of the sprinklers, the diamter of throw in feet and the angle of the wet sector in degrees (for part circle sprinklers) by

$$\text{Application Rate} = \frac{50{,}000 \times \text{GPM}}{\text{ft.}^2 \times \text{Degrees}} = \text{in./hr.}$$

and for the sample evaluation (See Form II-4 parts 2, 3 and 7) which wets 250 ft. to the left and 160 ft. to the right with the part circle sprinklers set for a 15^o dry sector which gives (360 - 15) = 345^o wet is

$$\text{Application Rate} = \frac{50{,}000 \times 500}{(410)^2 \times 345} = 0.43 \text{ in./hr.}$$

Analysis and recommendations

Many of the observations and some recommendations which can be made from the additional data on Form II-4 and the DU and PE computations have already been referred to here and/or in the other sprinkler evaluation sections.

The pressure of 100 psi at the nozzle is ideal for good breakup. The losses in the drive turbine (10 psi) and the 4-inch by 660-foot flexible hose (27 psi) are reasonable.

Infiltration did not appear to be a problem. The soils were able to receive the light application at a rate of 0.43 in./hr. with no problem and the tow path remained relatively dry.

Under-irrigation. After reviewing the full value of the operation it was concluded that the amount of under-irrigation found was reasonable. There is considerable summer rain in the area which may fill in the cummulative smd along the center of the strips; furthermore, the physical limitations of the field size and water supply made large increases in the average depth of application impractical. Only improvements in DU and possibly slightly higher flow rates would be practical.

Improvements. The only major improvement necessary would be to increase the DU. However, it is not reasonable to reduce the tow path spacing during the season and if it were reduced, the numbers of tow paths and consequently the number of days between irrigations would need to be increased.

Several practical possibilities exist: increase the angle of the dry area up to between 90° and 120°; try a taper bore nozzle; and/or increase the nozzle size. These changes should be tried and tested First change the angle, then try a taper bore nozzle, which will have greater range, and then try the next larger ring nozzle.

Edge effects. The outside tow paths of the present system are placed 150 ft. inside of the field boundaries. The field was laid out similar to Figure II-18. There were 8 tow paths across the 2610 ft. (2640 ft. less a 30 ft. road right-of-way) width of the field.

The outside tow paths were 150 ft. from the edges. From the data on Form II-4 part 3, this should give a reasonable application (1.7 in.) on the down wind side but results in very light (0.4 in.) watering along the up wind side.

The traveler was started at the top edge of the field and stopped on the lower edge. This results in considerable overthrow but does a fair job of watering the ends of the field (See Figure II-18).

The full length of the 660-foot hose was needed as it is drug through the 1320-foot length of the tow paths.

Summary

The DU of 71% and the PE of 66% found in the evaluation are typical of supplemental irrigation systems used on corn. The main system problems are associated with a poor DU in which the dryest part of the pattern occurred in the mid portions of the strips between tow paths. Improvements in DU may be possible by changing the dry angle of the sprinkler or the sprinkler nozzle.

CHAPTER III

TRICKLE (OR DRIP) IRRIGATION

Trickle irrigation is a system for supplying filtered water (and fertilizer) directly on or into the soil. Spraying is eliminated and water is allowed to dissipate under low pressure in an exact predetermined pattern. (See Figure III-1.) The outlet device which emits the water into the soil is known as a "trickler". Tricklers dissipate the pressure in the pipe distribution networks by means of a narrow nozzle or long flow path, thereby decreasing the water pressure to allow discharge of only a few gallons per hour. After leaving the trickler water is distributed by its normal movement through the soil profile; therefore, the area which can be watered from each trickler source point is limited by the constraints of the water's horizontal flow.

In trickle irrigation the objective is to provide each plant with a continous readily available supply of soil moisture which is sufficient to meet transpiration demands. Trickle irrigation offers unique agronomical, agrotechnical, and economical advantages for the efficient use of water. The main disadvantages of trickle irrigation systems are sensitivity to clogging, salinity build up, and poor soil moisture distribution.

Irrigation Depth and Interval

Since only part of the soil volume is wetted as in orchard sprinklers the determination of the amount (depth or volume) of application per trickle irrigation cycle and irrigation interval, are unique.

The Management allowed Deficiency, MAD, at which irrigation should be started depends on the soil, crop and water-yield-economic factor. Since this relationship is not quantitatively expressed, the MAD is usually taken as 30% for drought-sensitive crops and up to 60% for non-sensitive crops.

The percentage of wetted area as compared to the whole irrigated area, P, depends on trickler discharge, trickler spacing and the soil type. A "right or proper" minimum value to P has not been established. However, one can conclude that systems with high P values: provide more insurance in case of system failures; should be easier to schedule; and bring more of the soil system into action for nutrient storage and supply.

Considering the current state of knowledge a reasonable design objective is to wet at least on third (P = 33%) of the potential root volume of soil. Of course in areas with considerable supplemental rainfall, lower P values may be acceptable. On the other hand, P should be held below 50 or 60% in wide spaced crops since many of the advantages of trickle irrigation depend on keeping the strips between rows relatively dry.

Much of the material which follows will depend on an understanding of the utilization of the field data and analysis presented in the section on orchard sprinklers.

Figure III-1. Typical field layout of trickle irrigation system.

Evaluation

The data needed for an evaluation of a trickle system consists of determining the:

1. Rate of discharge from and the pressure near a number of tricklers throughout the system.

2. Duration and frequency of normal irrigation.

3. Soil moisture deficiency, smd, and Management Allowed Deficiency, MAD, in wetted areas.

4. Trickle locations relative to trees (or plants).

5. Tree (or plant) spacing and size.

6. Percent of area wetted.

7. Pressure losses at the filters.

8. Changes in trickler discharge after cleaning.

9. Sequence of operation.

Equipment needed

The main equipment items needed for collecting the field data are:

1. Graduate cylinder with 250 ml capacity.

2. Funnel.

3. Pressure guage (0-50 psi) with "T" adapters for temporarily installing it at either end of the trickler lateral hoses.

4. Tape measure.

5. Stop watch.

6. Soil auger, probe, and shovel.

7. Forms for recording data.

Field procedure

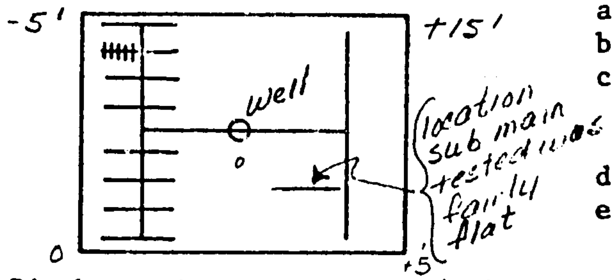
Fill in the data blanks of Form III-1, as the field procedure is conducted in the following stpes:

1. Locate 4 trickler laterals along an operating manifold (See Figure III-2). Choose one near the inlet end, two evenly spaced in the mid section and one near the far end.

2. Measure the inlet and downstream end pressure of each of the laterals under normal operation. On the inlet end, this will require disconnecting the lateral hose, installing the pressure guage and reconnecting the hose before taking a reading.

FORM III-1. TRICKLE EVALUATION DATA SHEET

1. Location *Ranch 14*, Observer *JFA*, Date *Aug 1, 1971*
2. Crop *Citrus*, Spacing *22* ft. x *22* ft., Tricklers/Tree *4*
   Age *7 yr*, Comments: *looked good 1st year under tricklers*
3. Soil *silt loam*, Comments: *no problem with infiltration*
4. Filter performance *fair - according to the operator*
   Pressure at inlet *60*, at outlet *55* psi
5. Trickler make *sp*, model *flushing*, spacing *5* ft., rated at *3* gph at *30* psi, Comments: *orifice type*
6. Hose diameter *1/2* in., material *pvc*, length *150* ft., spacing *22* ft.
7. System layout and topography (use back of sheet if needed)



8. Operational sequence and general comments:
   a. Number of blocks *4*
   b. Irrigation interval *1* days
   c. Duration of irrigation average *6* hrs. this irrigation *6* hrs.
   d. System flow *—* gpm
   e. Comments: *might be better to go to a longer interval*
9. Discharge in *1.0* min. (1.0 gph = 63 ml/min.)

Trickler Location		Lateral Location in this Manifold: inlet end ml	inlet end gpm	1/3 down ml	1/3 down gpm	2/3 down ml	2/3 down gpm	far end ml	far end gpm
inlet end	*A*	*132*	*2.10*	*160*	*2.54*	*192*	*3.04*	*195*	*3.10*
	B	*160*	*2.54*	*188*	*2.99*	*140*	*2.23*	*205*	*3.26*
	Av		*2.32*		*2.77*		*2.64*		*3.18*
1/3 down	*A*	*160*	*2.54*	*195*	*3.10*	*175*	*2.78*	*169*	*2.69*
	B	*168*	*2.66*	*158*	*2.50*	*170*	*2.70*	*180*	*2.86*
	Av		*2.60*		*2.80*		*2.74*		*2.78*
2/3 down	*A*	*187*	*2.97*	*146*	*2.31*	*125*	*1.99*	*144*	*2.29*
	B	*175*	*2.78*	*155*	*2.46*	*155*	*2.46*	*175*	*2.78*
	Av		*2.88*		*2.38*		*2.23*		*2.54*
far end	*A*	*170*	*2.70*	*190*	*3.02*	*210*	*3.34*	*151*	*2.39*
	B	*125*	*1.99*	*135*	*2.15*	*166*	*2.62*	*130*	*2.07*
	Av		*2.34*		*2.58*		*2.98*		*2.18*

		inlet end	1/3 down	2/3 down	far end
10.	inlet psi / end psi	*47.5* / *46.0*	*45.0* / *43.5*	*45.5* / *45.0*	*45.0* / *44.0*
11.	Wetted area ft^2, % of total area	*150* / *31%*	*125* / *26%*	*140* / *29%*	*145* / *30%*
12.	smd (next block)-in.	*X*	*X*	*X*	*X*

13. Average discharge of tricklers in block: Total block *83.88* gph/ *32* tricklers = *2.62* gph; low 1/4 *17.13* gph/ *8* tricklers = *2.14* gph
    9.07 / *4* = *2.27*

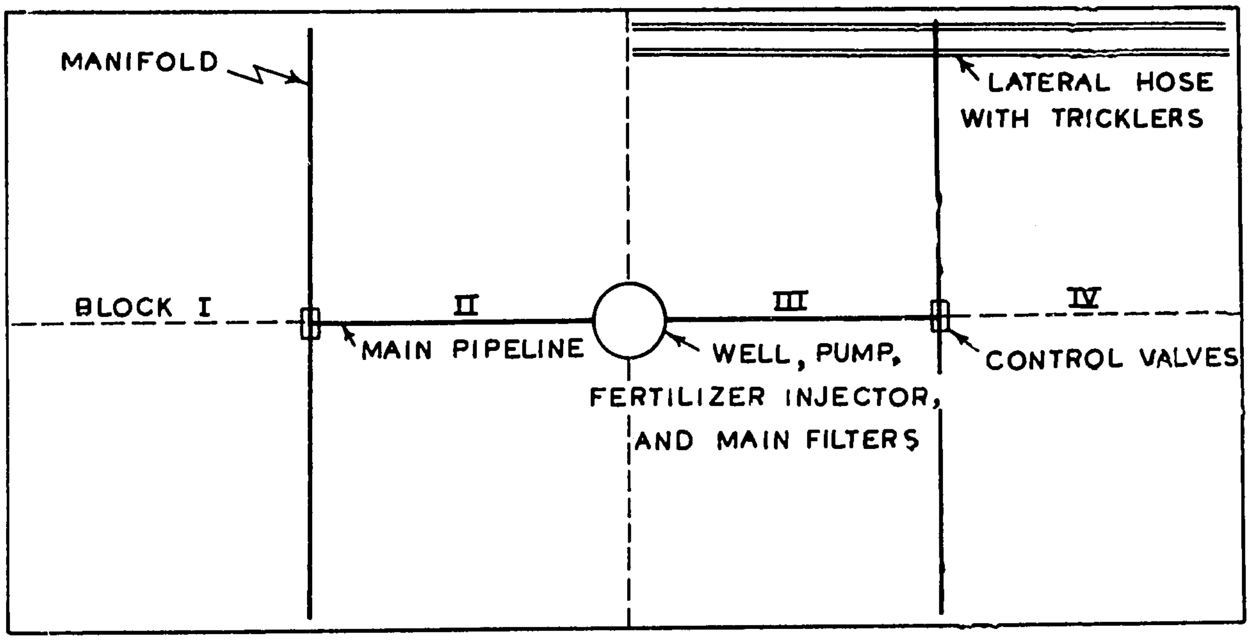


Figure III-2. Typical trickle irrigation system layout.

3. Measure the discharge from 2 adjacent tricklers at 4 different tree (or plant) locations on each of the 4 selected test laterals (See Figure III-3).

Collect the flow for a full number of minutes, 1, 2, 3, etc., to obtain a volume between 100 and 250 ml for each trickler tested. Convert each reading to ml/min. before entering in the data Form III-1. (To convert ml/min. to gallons per hour, gph, divide by 63.)

The above 3 steps will produce 8 pressure readings and 32 discharge values at 16 different tree locations.

4. Check the percentage of the soil volume which is wetted at one of the tree locations on each of the test laterals. (It is best to pick a different relative tree location on each lateral.)

Use the probe, soil auger, or shovel whichever seems to work best for estimating the areal extent of the wetted zone about 6 to 12 inches below the surface around each tree. The percentage volume wetted is determined by dividing the wetted area by the surface area between 4 trees.

5. If an irrigation interval of several days is being used, check the smd in the wetted volume near a few representative trees in the next block to be irrigated. This is difficult to do and will require averaging samples taken from several positions around each tree.

Figure III-3. Field measurement of trickler discharge.

6. Fill in the blanks on Form III-1 dealing with trickler and filter specifications and operation, topography, general system performance and crop appearance.

Emmission Uniformity, EU

In order to determine if the system is operating at an acceptable and economical efficiency, the uniformity should be evaluated by calculating the EU which is

$$EU = \frac{\text{minimum rate of discharge per plant}}{\text{average rate of discharge per plant}} \times 100$$

in which the average of the low quarter will be used as the minimum.

Since there were 4 tricklers per tree in the citrus grove which was evaluated, the discharges from the two (A and B) tricklers at each tree can be averaged. The minimum rate of discharge (or low 1/4) is then the average discharge of the lowest 4 of these (average) discharges per tree or 2.27 gph for the sample evaluation. (See Form III-1 parts 9 and 13.) The average rate of discharge per tree was 2.62 gph which gives

$$EU = \frac{2.27}{2.62} \times 100 = 87\%$$

Utilization of field data

In trickle irrigation all the system flow is delivered to the crop. There is essentially no opportunity for water loss except at the tree (or plant locations). Therefore, the uniformity of the emmission from the tricklers is of primary concern. The individual trickler locations (or the tree locations when there are several tricklers closely spaced) can be thought of in much the same manner as the container positions in sprinkler tests.

Another item of principal importance is the percentage of the total potential root volume that receives water.

Application storage Efficiency, E_a

As with orchard sprinklers, which also only wet part of the soil surface (See Orchard Irrigation), the E_a gives a measure of the overall operational efficiency of the systems (providing adequate irrigations are applied). The AE used in all the other evaluation procedures can not be used for trickler and orchard sprinkler systems which only wet part of the area since the minimum depth would be zero.

$$E_a = \frac{\text{average depth stored}}{\text{average depth applied}} \times 100$$

In computing the *average depth stored* it is assumed that all of the water discharged from the tricklers up to the smd is stored. Water in excess of smd is lost to deep percolation.

It is always difficult to estimate the smd in the wetted portion of the root zone under trickle irrigation even when the irrigation interval is several days. For the sample evaluation where irrigations are applied every day, it is practically impossible to estimate the smd.

However, with good management and full irrigations to replenish all the water consumed by the plants, the deep percolation losses will range in the vacinity of 10%. Thus, the E_a under full irrigation can be estimated by

$$E_a = 0.9 \times EU$$

which for the sample test is:

$$E_a = 0.9 \times 87\% = 78\%$$

The average depth applied per tree to the wetted area is computed from the average gph per trickler, the number, N, of tricklers per tree, the area wetted per tree in ft.^{2} and the hours of operation

$$\text{Av. depth applied to wet area} = \frac{1.6 \times N \times gph \times hrs.}{ft.^2} = \text{inches}$$

which for the sample evaluation (See Form III-1 parts 8, 11, and 13) is

$$\text{Av. depth applied to wet area} = \frac{1.6 \times 4 \times 2.62 \times 6}{140} = 0.72 \text{ in.}$$

The average depth applied to the total area is useful for managing the irrigation schedule. This overall average depth applied can be found by substituting the tree spacing for the wetted area in the previous formula. For the sample evaluation with a tree spacing of 22 ft. by 22 ft.

$$\text{Av. depth applied} = \frac{1.6 \times 4 \times 2.62 \times 6}{22 \times 22} = 0.21 \text{ in.}$$

Analysis and recommendations

A number of observations and some recommendations can be made from the additional data on Form III-1 and the EU and E_a computations.

The pressure differences throughout the operating block studied were very small (See Form III-1, part 10). With orifice type tricklers, pressure variations as great as 20% would still give good results. With the long tube type tricklers, pressure differentials should be held to about 10%.

The uniformity of application as expressed by the EU of 87% was fairly high. Since the pressures were very uniform it appears that most of the lack of uniformity resulted from variations in the tricklers. This can also be seen by studying the table on Form III-1 part 9. The A and B trickler discharges at the same location (which would have almost identical pressures) were often quite different.

The tricklers used were of the automatic flushing orifice type. The variations in discharge discussed above were probably due to manufacturing tolerance difficulties.

It is interesting to note that the tricklers were operating at pressures in the vacinity of 45 psi and the average discharge was 2.62 gph (See Table III-1 parts 5, 10, and 12). This is considerably off of the rated 3.0 gph at 30 psi and indication that the orifices may be slowly closing (or clogging).

Variable clogging can cause large differences in flow from non-flushing tricklers even though manufacturing tolerances may be very close.

Some tricklers can be manually flushed. On systems with this type of trickler, a check should be made to determine the change in flow before and after flashing.

The filter seemed to be performing reasonably well. It was not excessively clogged at the time of the study since the pressure loss across it was only 5 psi (See Form III-1, part 4).

The elevation differences throughout the system were not extreme (See Form III-1 part 8) so the other operating blocks should produce similar uniformities. With an up-hill elevation difference of more than 10% of the average pressure head beyond a control valve, it is difficult to achieve a high EU. Obviously it is important that each control valve be accurately adjusted to achieve uniform pressures throughout the entire orchard.

The percentage wetted soil root volume (or area) was on the low side. It was only 30% which is below the recommended minimum discussed in the introduction (See Form III-3 part 11).

Improvements. A major area for improvement would be to increase the percent of wetted area. This could be done by increasing the irrigation interval to 2 days or by adding one or two extra tricklers at each tree and decreasing the operating pressure.

Going to a 12-hour irrigation every 2 days instead of the present 6 hours per day is an interesting possibility, since deeper applications wet more soil volume. Also there seemed to be no infiltration problems and the *average depth applied to the wet areas* of 0.72 in. could easily be doubled without exceeding the smd at a MAD of 30%.

It appears that the trickler discharges are gradually decreasing and the system is designed for a greater flow than was observed. Thus adding extra tricklers could restore the system capacity back to the original (4 x 3 gph) = 12 gph per tree at an average operating pressure of 30 psi.

The only way to improve the EU would be to replace the tricklers which would be very expensive and not warranted at this time.

The average depth applied of only 0.21 in. per daily cycle seems to be in the marginal side for a mature orchard in the test area. This would be increased to 0.24 in. if the total discharge per tree were restored to the original design of 12 gph per tree.

<u>Summary</u>

The EU of 87% and estimated E_a of 78% of the system are good. The main system problems are associated with a marginal amount of soil wetted (only 30%) and low system flows. It was recommended to the operator that he try scheduling the irrigation to apply water for 12-hour periods, every two days instead of the current 6 hrs. per day. It was also suggested that the tricklers be replaced or an extra trickler be added at each tree to restore flow rates back to the design value (and also increase the percent of wetted area.)

CHAPTER IV
FURROW IRRIGATION

Simple Furrow Evaluation

Simple techniques are often useful to provide information for identification and correction of operational problems. Most of the data can be obtained from questioning the irrigator or making simple observations and measurements.

Evaluation

For both simple and full evaluations, the following basic criteria of good irrigation should be considered:

1. Is it dry enough to irrigate? Withholding water too long will detrimentally stress the crop. Irrigating too soon often contributes excess water to a high water table, thus encouraging pests, diseases and increasing labor.

2. Is it wet enough to stop? In other words, has an adequate but not excessive depth of water been infiltered? And has the moisture spread laterally enough?

3. Has water been uniformly distributed along the furrow? Good uniformity is usually achieved if the stream reaches the lower end, without erosion, in about 1/4 to 1/3 of the time of irrigation.

4. Is there much runoff? A little water either ponded or running off at the lower end is essential for practical operation.

5. Is the water supply and system capable of delivering water for efficient and convenient water and labor use? Supplies should be large and flexible in both rate and duration. Streams should be large enough to advance quickly and shut off when not needed.

Equipment needed

Onlv a soil probe and a soil auger are needed for the simple evaluation.

Procedure

The following illustration will utilize the simple part of the data as obtained for the full evaluation studv of an actual irrigated corn field.

Soil moisture deficiency should always be the first concern, "Is it dry enough to irrigate?" The answer is too often based on guesswork or rigid schedules which usually results in applying water too soon. For this example study, in 660-foot long corn furrows spaced at 36 inches, a soil moisture deficiency, smd, check was made. It indicated an irrigation was needed and that the smd was about 3.6 in.

The above information was obtained using the Soil Moisture and Appearance Relationship Chart A-1 in Appendix A. The soil auger was used in the sandy loam soil to obtain soil samples at one foot increments to a depth of 4 feet. The top foot was estimated to be quite dry with a high smd -- 1.6 in./ft. out of 1.8 in./ft. of total available moisture. The second, third and fourth foot samples appeared to have smd values of 1.2, 0.6, and 0.2 in./ft., respectively. This gives a total smd of about 3.6 in.

The corn roots at that time had extended to only about 3.5 ft. and for the cool climate and expanding root zone a MAD of 60% was acceptable. This gives a MAD of 1.8 in./ft. x 3.5 ft. x 60% = 3.8 in. The farmer was applying water at about the proper time since the smd of 3.6 in. was about equal to the MAD of 3.8 in.

Adequacy of irrigation is easily determined with fair accuracy in the field during irrigation with the probe as described in Appendix G. It can also be determined analytically. The adequacy of irrigation answers the second important question, "Is it wet enough to stop irrigating?"

At the upper and lower ends of several furrows, the probe was used to determine the depth of the wetting front. The probe penetrated easily where the soil was nearly saturated, but resistance to penetration increased drastically at the wetting front.

When the field work for this evaluation was completed in about two hours, at the upper end of the furrows the probe penetrated almost 1.5 ft. and little less than 1.0 ft. at the lower end. Also, pushing the probe into the soil at an angle indicated the lateral spread had quite a ways to go. To properly use the probe, the checks need to be made near the end of the irrigation time to know when to stop irrigating. For this field, water should have been run until probing at the lower end of the furrow showed the wetting front had penetrated to about 2.5 ft. The excess top soil moisture would then drain down by the next day to satisfy the small deeper deficiency between 2.5 and 3.5 ft. All water applied after the penetration is sufficient for a full irrigation is lost! Therefore, probing is essential for deciding when to stop irrigating. No actual check was made near the end of the irrigation time, which was 10 hours, but the irrigator should and could have easily done so.

Using knowledge and figures from the full evaluation, it is believed that the probe would not have penetrated deeply enough in 10 hours to indicate an adequate irrigation, since computations show it would take over 14 hours. It also probably would not have fully wet between rows. Both the depth and lateral wetting must be checked at the end of irrigation. For the learning process, a trench should be dug across the furrow to see the vertical and horizontal wetting pattern. This should be done about half way through and after irrigation.

Uniformity of application is important for efficient use of water. In furrow irrigation on uniform soils, uniformity of infiltration is pretty well assured by getting the water to the far end of the furrows quickly. The desirable Advance Ratio, R, is expressed as a ratio between the time of advance, T_{adv}, needed to reach the lower end of the furrow, and the time of irrigation, T_i, needed to infilter the desired depth of water at any point. If this ratio is about 1/4, good uniformity may be obtained. During this test the irrigation stream advanced the full 660 ft. in about 1 hour leaving 9 more hours for the water to run. The Advance Ratio of 1/9 is lower than necessary for reasonable uniformity, and 1/14 would be more extreme. For example, using information from the full evaluation with Advance Ratios of 1/5, 1/4, 1/3 and 1/2, the corresponding Distribution Uniformities, DU, are: 0.94, 0.93, 0.91 and 0.87 for the tested soil and MAD. This shows that for reasonable Advance Ratios less than 10% of the water goes too deep.

Runoff streams two hours after beginning to irrigate appeared to be about half the size of the inflow streams. The irrigator planned to run it about eight hours more! The streams reached the ends of almost all furrows in less than one hour. Therefore, runoff would continue for more than nine hours. Since the intake rate decreases with time, the runoff streams would continually be increasing until the inflow stream was shut off.

Furrow stream size can be estimated by dividing the system capacity by the number of furrows being irrigated simultaneously. In this case, the irrigator had a well which discharged 960 gpm and he usually sets 50 to 55 siphons; consequently, the streams were about 18 gpm. Since the streams reached the end of the furrow more quickly than was desirable, they should have been smaller.

Utilization of field data

The observations and quick analysis do not provide enough information to indicate the best modifications, but they provide a good start. The depth of water applied to the field can be calculcated by

$$\text{Depth Applied} = \frac{96.3 \text{ x gpm x hours}}{\text{furrow spacing ft. x length ft.}}$$

In this case

$$\text{Depth Applied} = \frac{96.3 \text{ x } 18 \text{ gpm x } 10 \text{ hrs.}}{3 \text{ ft. x } 660 \text{ ft.}} = 8.7 \text{ in.}$$

The depth applied was 8.7 in. but the smd was only 3.6 in. with the 10-hour irrigation. Very little water, if any, went too deep, so there must have been an excess of runoff. This checks with the observation that runoff was about half of the inflow at the end of two hours. More than enough water was applied, but probably not enough infiltered.

Analysis and recommendations

The analysis showed the following:

1. It was dry enough to irrigate, since the smd was 3.6 in. and the MAD was 3.8 in.

2. Uniformity was far better than needed, since the stream reached the end very quickly and the Advance Ratio was very low (1/9).

3. There was a great deal of runoff, since too large a stream was used and it reached the end early in the irrigation.

4. The water supply was not flexible in rate, but adjustments could have been made by starting more furrows with smaller streams. Furthermore, additional furrows could be started with water saved by cut-back irrigation, in which the inflow stream is reduced when runoff begins. However, this is not convenient for labor, so it was not done.

To improve system efficiency, the following recommendations can be made:

1. Make smd checks to determine or confirm frequency and to avoid cumulative deficiencies in the lower part of the root zone. Even though the frequency of irrigation was about correct as the farmer was doing it, a cumulative smd might occur.

2. Check depth of infiltration and spread using a probe.

3. Use a smaller stream which would take about three hours to reach the end of the furrow and permit running more furrows. Or since the streams were not erosive, a longer furrow could be used with the same stream size. Either of these saves labor and still provides excellent uniformity as long as the Advance Ratio, R, is held below 1/3.

The stream would have to be run for a longer application time to assure adequate infiltration, as the plants grow larger, or if the practice of intentional under-irrigation is used. The correct duration could easily be checked with the probe. If the longer duration is not practical from a labor viewpoint, some other changes could be made. For example: the furrow shape could eaily be made wider; MAD or the row spacing could be reduced to shorten the time of irrigation; or an automatic pump shut-off could be installed. The reduction of MAD would require more frequent irrigations, possibly needing one more during the season, therefore, involving more labor.

4. Runoff could be reduced by the following: install a tailwater re-use system; cut-back the furrow streams about an hour after the flow had reached the end; use a smaller initial stream; or use longer furrows.

A return flow pump system putting water back into a reservoir is sometimes a very practical and economical way to save water and labor. Just pumping the water back into the supply ditch is not good practice. It requires starting more and more furrows with each having different shut-off times, which is awkward for labor if good efficiency is desired.

The cut-back stream procedure would not be convenient with the setup the farmer was using. His ditch checks were solid earth embankments with a plastic cover for erosion control. These solid embankments could not be easily lowered to reduce head thereby changing all the siphon flows simultaneously. Converting to adjustable checks would simplify cut-back irrigation. Other ways to make cut-back streams are using two smaller siphons to start the initial streams and removing one to reduce flow or raising the end of each single large siphon. However, with a supply ditch receiving a constant inflow, the cutting back of the streams flowing into the furrows by any method leaves more water in the ditch. This water must be used to progressively start more furrows which increases labor and requires different shut off times.

Aside from building a new distribution system, the most practical way to reduce runoff waste is to use longer furrows or smaller streams which reach the end in about 1/3 or even 1/2 the irrigation time. These would have very little runoff although the application time would be appreciably longer. More water would penetrate too deep at the upper end resulting in a lower Distribution Uniformity, DU, but more efficient labor and water use would be obtained. A full evaluation study would make it possible to anticipate the effect of various changes.

5. The irrigator should be the person making the simple evaluations, since some of the checks need to be made at the end of irrigation. A full evaluation would provide answers to the following questions giving a detailed basis for making economic studies for improvement. How much water is wasted? What is the Distribution Uniformity, the Actual application storage Efficiency, and the Potential irrigation system Efficiency? What would be the cost and saving from building a reservoir and new system pumping the well steadily at a lower rate? How long should the furrows be? What is the best stream size? Would a change in furrow shape or spacing be helpful? Would a return flow system be desirable?

Summary

The soil moisture deficiency and the frequency were about right, but the correctness should be verified by an smd check. The Distribution Uniformity was too high, so smaller furrow streams could be used. Runoff was very large, wasting over half of the water applied and could best be reduced by using a smaller furrow stream in more furrows or the same stream in longer furrows. The flow from the well was at a usable rate, but a larger flow would reduce labor costs.

Full Furrow Evaluation

Detailed evaluations provide information for identifying existing problems, making many possible changes to correct them, making economic comparisons of procedures and methods, and furnishing background for design of systems under similar conditions.

Evaluation

The technique of evaluation consists of determining, in the field at a typical location and with the proper moisture condition, the following: 1. the flow rate of several different stream sizes ranging from too large to too small, 2. the rate at which the various streams advance, 3. the maximum stream size as limited by erosion or furrow capacity, 4. the intake rate of the furrow, 5. furrow condition - new, re-used, firm, loose, etc., 6. the soil moisture deficiency, 7. the maximum furrow spacing which will allow adequate wetting of the soil between the furrows within the time of irrigation, and 8. the adequacy of the irrigation as to depth and lateral spread.

Additional data may be gathered such as: 1. furrow shape, wetted width, and depth, 2. furrow gradient, 3. water recession, 4. rate of run-off from each stream, 5. rate of inflow and outflow for cut-back streams, 6. rate of advance with a cut-back stream, 7. soil texture and profile, 8. maximum water delivery capacity, 9. tests of furrows of various shapes, and 10. cylinder infiltrometer test.

After the field data is obtained and plotted, a study will permit the determination of: 1. Distribution Uniformity, 2. Potential irrigation system Efficiency, and 3. Actual application storage Efficiency of the system as it is being used.

A more detailed study will point out the improvements that may be made, some of which may or may not be economical. Such a study might include the following: 1. changing stream size and rate of advance, 2. changing length of run, 3. changing furrow spacing, 4. changing furrow shape, 5. changing soil moisture deficiency, smd, at which irrigation is started, 6. using alternate side irrigation, 7. using continuous furrows with supplemental inflow, 8. installing a reservoir for flexible delivery, 9. adjusting factors to make duration of irrigation match duration of water delivery for convenience of labor where a reservoir is not practical, 10. installing a return flow or reregulating system to save runoff and labor, 11. revising delivery system to give more flexible deliveries to save water and labor, and 12. using furrows in conjunction with sprinklers.

Equipment needed

1. Surveying tape to locate stations.
2. Laths or stakes to mark stations and a hatchet to drive them.
3. Watch.
4. Flow measuring devices such as small Parshall flumes with 1 or 2 inch throat, orifice plates, spiles, siphons, V-weirs, calibrated containers, etc., and the necessary time or head measuring instrument. The devices used should be capable of accurate flow measurements when used to determine the furrow intake rate. (See Appendix C.)
5. Shovel.
6. Soil auger.
7. Soil probe.
8. Forms for recording data.

Additional equipment for more detailed work would include:

9. Surveying equipment to determine furrow gradient.
10. Cylinder infiltrometer equipment.
11. Soil moisture sampling equipment.

Field procedure

1. Choose a location in the field that is typical as to conditions. The soil should be uniform throughout. A steady source of water should be available from which streams desirably of a constant size can be turned into the furrows. (See Appendix B for detailed description of stream control methods.)

2. Select three or more furrows. They may be alternate furrows to facilitate patroling the streams without walking on wet soil. If the furrows are new with loose soil over a plow pan or other conditions in which water moves rapidly sideways, all furrows should be run to prevent abnormal lateral flow.

3. Set stakes along the furrow, usually at 100-foot stations, but a minimum of six. The zero station may be set a short distance from the inlet end of the furrow to give flows a chance to stabilize before taking measurements. Elevations may be surveyed or gradient otherwise determined, but this is not essential for any specific evaluation.

4. Prepare flow measuring devices at zero station of all test furrows.

5. Set flow measuring devices for furrow intake rate test. (See Appendix C for details of such devices.) These should be set in the furrows carrying moderate streams, avoiding small or erosive ones. It is desirable to check intake at more than one location or furrow. The location is usually at the upper end of the furrow to provide a longer test duration. For rapid to moderate intake soils, the devices may be set 100 ft. apart for inflow-outflow measurements. For slower intakes 200 ft. may be used, or several furrows may be combined. Flow measuring devices may be set at the terminal end of the furrows to measure runoff.

6. Determine the soil moisture deficiency and how closely it agrees with the desired Management Allowed Deficiency, MAD. (See Appendix A.)

7. Set at least three, though preferably four, constant-flow streams with different flow rates in each to bracket the possible range in size. If flow rates do vary, the change should be noted. One stream should be large enough to cause a little erosion unless limited by furrow capacity, and one should be so small as to barely reach the lower end. Desirably two different intermediate sizes should be run. The larger of these typically has a flow rate $Q_{gpm} = 10/S$, where S is the furrow slope in percent, but judgement will have to be used. Where practical, a set of each of used and new furrows should be tested, and in cultivated orchards furrows near the trees and in the middles should both be tested since re-use, soil structure, and moisture content have a large effect on stream size, intake rate, and advance rate. (See Figure IV-1.) Furrows of other sizes and shapes may also be observed to broaden the irrigator's choice for possible revision.

8. Record the stream size flowing in each furrow.

9. Record the time each stream reaches each station. These may be plotted in the field when they are recorded.

10. Record the intake rate flow data following instructions on Form IV-1. The test should run for the duration of the irrigation, but may be less. For the slower intake soils, tests may be shortened to three hours but not less than it would take a moderate stream to reach the furrow end.

11. Observe the furrow for erosion or overtopping. Estimate the maximum usable stream size. In new furrows the loose soil will muddy the water at first without it being considered erosion. Also, some erosion

FORM IV-1. FURROW EVALUATION DATA SHEET

location Santa Maria observer LM date 10 May 71

furrow identification Q= 9.2 shape ⌣ condition good age reused

soil compact s.l. moisture content dry, norm slope .002

comments flumes placed at 0+00 and 2+00. Used 9.2 gpm as average

TIME			INTAKE				
			Station A 0+00		Station B 2+00		
1	2	3	4	5	6	7	8
Watch Time	Difference of time	Cumulative time	1" Parshall	Flow Rate gpm	1" Parshall	Flow rate gpm	gpm/100'
8:27		0	2"	9.4			
33	6	6	1 15/16	9.0	1 6/16	5.2	4.0 2.0
38	5	11	2	9.4	1 8/16	6.0	3.2 1.6
49	11	22			1 9/16	6.4	2.8 1.4
9:03	14	36	1 15/16	9.0	1 10/16	6.8	2.4 1.2
20	17	53			1 11/16	7.2	2.0 1.0
47	27	80		9.4	1 11/16	7.2	2.0 1.0
10:24	37	117	2		1 12/16	7.6	1.6 .8
Accuracy range			± 1/32	± .2	± 1/32	± .2	±.4 ± .2

used 9.2 as average

furrow identification Q= 17.5 shape ⌣ condition good age reused

soil compact s.l. moisture content dry, norm slope .002

comments used 17.5 as correct flow

TIME			INTAKE				
			Station A 0+00		Station B 2+00		
1	2	3	4	5	6	7	8
Watch Time	Difference of time	Cumulative time	2" Parshall	Flow Rate gpm	1" Parshall	Flow rate gpm	gpm/100'
8:29		0	1 15/16	18.0			
34	5	5	1 14/16	17.1	2 6/16	12.3	5.2 2.6
40	6	11	1 14/16	17.1	2 9/16	13.8	3.7 1.85
49	9	20			2 10/16	14.4	3.1 1.55
9:03	14	34	1 15/16	18.0	2 11/16	14.9	2.6 1.3
20	17	51			2 11/16	14.9	2.6 1.3
47	27	78			2 11/16	14.9	2.6 1.3
10:24	37	115	1 15/16	18.0	2 12/16	15.5	2.0 1.0
Accuracy range			± 1/32	± .4	± 1/32	± .3	±.7 ± .3

used 17.5 as average

1. First entry made when stream reaches midway between stations A and B. Second entry made a few minutes after stream passes station B. Subsequent entries made at increasingly longer intervals to obtain at least six entries.
2. Difference in time between successive watch times.
3. Summation of successive time increments. To be plotted versus 8.

4,6. Read on Parshall flume, orifice or weir. Show device and units used. If jug is used, show size and time to fill.

5,7. Conversion units if needed and corresponding g.p.m.

8. Difference between 5 and 7 adjusted to 100' if A and B are not 100' apart to give rate of intake in gpm/100'. Plot versus 3 on log log.

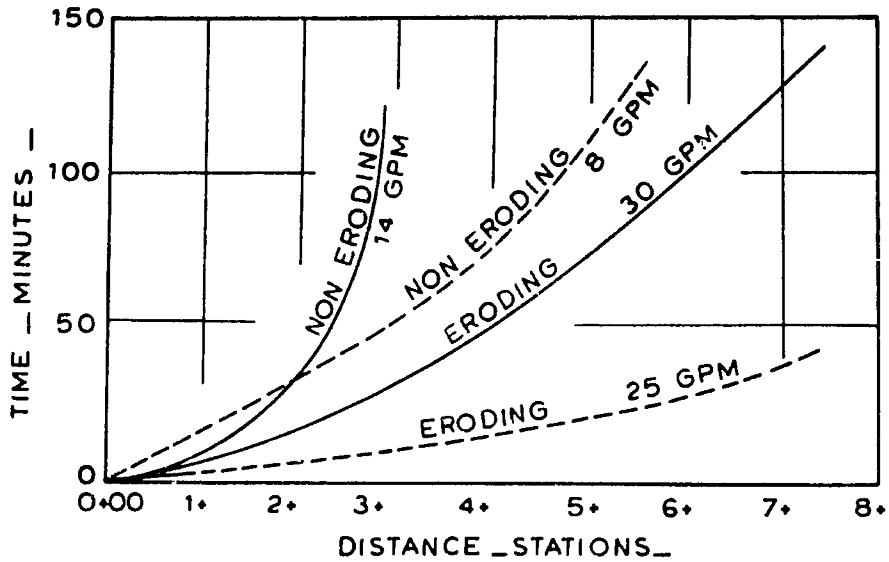


Figure IV-1. Effect of furrow condition, stream size, and soil moisture on advance rate.

will often occur at the turn out but become stable after a short time.

12. Observe outflow at the end of the furrows. Under circumstances requiring a detailed evaluation, the outflow should be measured at several time intervals, otherwise it may be estimated as a percent of the inflow stream and so noted. Cut-back streams are almost always desirable and practical where a properly designed system is used. One of the larger streams should be cut-back after appreciable runoff is occuring and the runoff observed or measured. Where furrows of excessive length can be tested there will be no runoff, only continued advance which permits an alternate, simple evaluation process to be used as described in the chapter of Border Irrigation.

13. If water is present in the furrow for appreciable time after it is turned off, (Time of Lag T_L), a notation of this time should be made as it represents extra time water may be infiltering. It is negligible in most furrows.

14. Depth of water penetration and lateral spread should be checked during irrigation by using a probe or soil tube to follow the wetting front. Evidence of plow pans is readily observed with the probe. The depth and width of penetration should be studied with an auger or soil tube a day after irrigation at several places along the furrow. More detailed

information can be obtained by cutting a trench across the furrow for visual observation of the pattern. This should be done at several locations in the furrow having the small stream so that the pattern can be seen for various du- tions of irrigation. This will assure that the furrow spacing is not too great to adequately wet the area.

Utilization of field data

The field information is best presented when plotted. The advance curves, which show the time water arrives at each station, are usually plotted on rectangular coordinates. The characteristics of each furrow should also be noted on the graph. It is practical to extrapolate advance curves beyond actual field length by plotting the data on full logarithmic paper on which they will have only a slight curvature. The recession curve, which relates the time and station location when water ceases to be on the surface, may be plotted, but it is usually assumed to be a horizontal, straight line unless field data indicates a significant deviation.

The intake rate curves showing the intake in gpm/100 ft. at any time are plotted on 3-cycle full logarithmic paper. The line for each test is plotted separately and the accuracy range noted. If they are similar, one line representing the typical condition may be added but used with the knowledge it may be plus or minus the actual value. (See Appendix D and Figure IV-2.)

Illustration of the evaluation procedure is presented from a test in a corn field 1300 foot long but cut in half by a supplemental supply ditch. The soil was a compact sandy loam and was estimated to have 1.8 in./ft. available moisture. The furrows were spaced at 36 in., were clean and had been used before. Alternate furrows were customarily irrigated at alternate irrigations. The gradient was 0.2%. Water was run in the furrows for 10 hours for convenience of labor. One siphon was used per furrow, and the flow was definitely non-erosive. Since a cut-back flow was not convenient, appreciable runoff water was wasted in a ditch just above the middle irrigation ditch. For the evaluation, siphons were set in three furrows. Two of them were partially plugged to reduce flow.

The soil moisture deficiency to a depth of 4 ft. was found in each foot from the chart in Appendix A to be 1.6, 1.2, 0.6, 0.2 in., **totaling 3.6 in.** with a 3.5 ft. root zone at the time, but expanding as the crop grew.

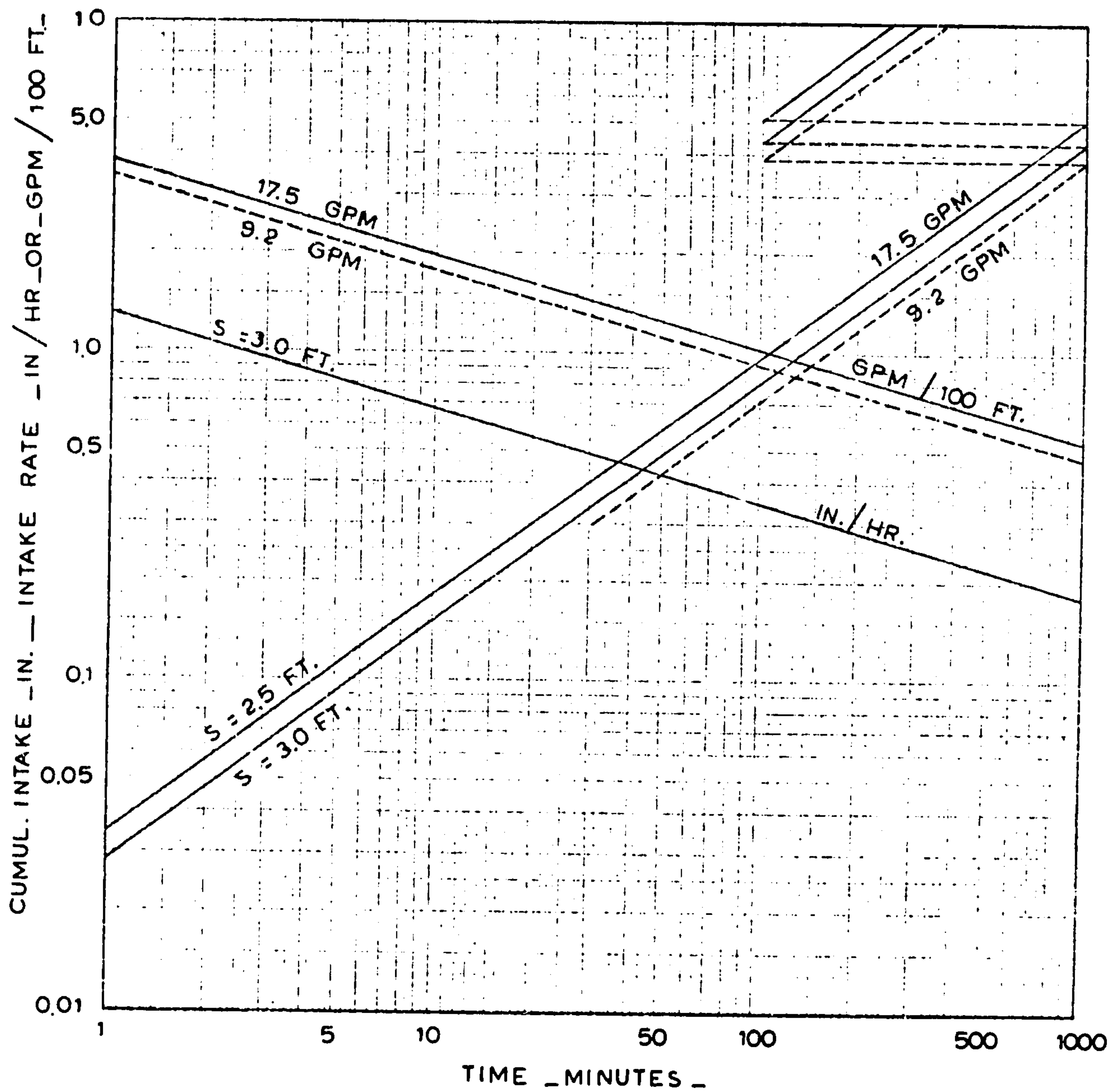


Figure IV-2. Furrow intake curves.

Intake rate data was found by setting 1-inch Parshall flumes at station 0+00 and station 2+00 in the furrows with the largest and the medium size streams. Flow rates into all three furrows were also measured by timing the flow from the siphons into a gallon jug. Good correlation with the Parshall flume was obtained for the medium stream, but because the largest stream filled the jug too quickly, the correlation in this furrow was poor.

As shown by the data on the Form IV-1, 200-foot sections of furrows were used, so there are two entries in column 8, the first representing total water intake and the latter the intake in the desired units of gpm/100 ft. The depth measurements, in the Parshall flumes, were made in a poor fashion with a ruler marked in sixteenths of an inch. These divisions are too large, and as shown on the data sheet for the first furrow and column 8, the resulting gpm values varied by ± 0.4 gpm/200 ft. or ± 0.2 gpm/100 ft. Finer divisions such as 0.01 in. or 0.001 ft. should be used. The bottom line, accuracy range, is important because in plotting each point, it must be appreciated that the ± value is a limit on the range anywhere within which the true value may occur. To clarify, such a range should be shown at each point when plotting, and the line drawn within the range as illustrated for the 17.5 gpm line on Figure IV-2. To increase the accuracy of measurements, a point gauge should be used to measure from a datum to the water surface, and to the bottom of the flume to obtain a zero reading. It may be improvised by fastening a wire to the end of a measuring scale.

The inflow values also show the problem of the low accuracy. It seems very probable for this test that an average of the readings in column 5 would be the correct one. However, average values should not be used if readings are accurate and changes in flow rate actually occur.

Intake rate and depth were found using the data shown on Form IV-1 and plotted on Figure IV-2, following the procedure in Appendix D. The two curves drawn for the two stream sizes are not averaged for this evaluation since they seem to have a relationship that may correctly be representing the slightly higher intake rate that should occur for a larger stream. The cumulative intake curves were extrapolated past 1000 minutes on the three-cycle logarithmic paper by setting back one log cycle.

When desired, the mathematical representation of the curves may be found by the following process. The equation for the plotted intake curve, which is usually a straight line on log-log paper, is of the form $I_{gpm}/100\text{ ft.} = KT^n$ where I is the intake rate gpm/100 ft., K the intercept when time T is one minute, and n is the slope v/h (vertical distance/horizontal distance) of the line. This slope is negative so n has a minus sign. Converting from gpm/100 ft. to inches per hour for specific furrow spacing, S, in feet may be closely approximated by dividing the equation by S.

$$I_{in./hr.(S)} = \frac{I_{gpm}/100\text{ ft.}}{\text{spacing in feet}}$$

Integrating the rate equation results in the equation for cumulative depth

$$D_{(S)} = K'T^{(n+1)}$$

where $K' = \frac{K}{60(n+1)S}$. K' is also the intercept of the cumulative curve at T equals one minute. All equations may be written from inspection of the plottings as shown on Figure IV-2.

$$I_{gpm}/100\ \text{ft.} = 3.8T^{-0.28} \qquad I_{in./hr.}(3.0\ \text{ft.}) = 1.27T^{-0.28}$$

$$D_{(3.0\ \text{ft.})} = 0.029\ T^{0.72}$$

Advance curves from data on Form IV-2 were plotted on Figure IV-3. Two of the curves were extrapolated to the full 1300 ft. This may be done by any of three ways. A French curve may be used for lines without much curvature such as the 17.5 gpm stream or for short extrapolations such as for the 4.0 gpm. Plotting may be done on log-log paper and extrapolated with a French curve. This was done for the 9.2 gpm stream and transferred to the rectangular coordinates. The third procedure involves finding the equation of the curve and computing the extrapolations.

An equation of the form $t_x = a(e^{cx} - 1)$ where t is minutes to reach distance x feet, has been found to fit many advance curves. The constants a and c may be found by obtaining the slope of the curve at two points, with due care for scale distortion, putting the slope values into the differential equation of the form $dt/dx = ac + ct$ for the two locations, and solving the two equations simultaneously.

Analysis

A simple analysis of the evaluation will show: 1. the uniformity with which water is distributed, Distribution Uniformity, DU, 2. what the potential of the system as it exists can be if used to its best advantage, Potential irrigation system Efficiency, PE, and 3. how well the irrigator is actually using the system, Actual application storage Efficiency, AE, i.e., whether the stream size and length of furrow are about correct, and whether the right amount of water is being applied.

Distribution Uniformity, DU, should be studied for several conditions, but for illustration only the 17.5 gpm stream and 3.0 foot furrow spacing

FORM IV-2. WATER ADVANCE and/or RECESSION DATA SHEET

Location Santa Maria Date 8/10/71 Soil Texture sl Moisture Deficiency dry Crop corn

Comments furrows were firm, reused, clean, ‿ shape, S=.002 Observer JLM

Adv. or Rec.	Adv.	Adv	Adv	
Identification	small #1	medium #3	large #5	
Stream Size	4.0 gpm	9.2 gpm	17.5 gpm	

TIME			
watch	diff.	cumu.	Station feet
8:22		0	0+00
39	17	17	1+
9:05	26	43	2+
39	34	77	3+
10:22	43	120	4+

TIME			
watch	diff.	cumu.	Station feet
8:24		0	0+00
31	7	7	1
39	8	15	2
50	11	26	3
9:03	13	39	4
22	19	58	5
46	24	82	6
10:03	17	99	6+50

TIME			
watch	diff.	cumu.	Station feet
8:27		0	0+00
32	5	5	1
37	5	10	2
44	7	17	3
53	9	26	4
9:03	10	36	5
15	12	48	6
22	7	55	6+50

Rod reading	Station feet

Note - For border-strip recession data, first time entry should be made when water started, second entry at time water turned off, third entry when recession starts, and all these entries should be at station 0 + 00.

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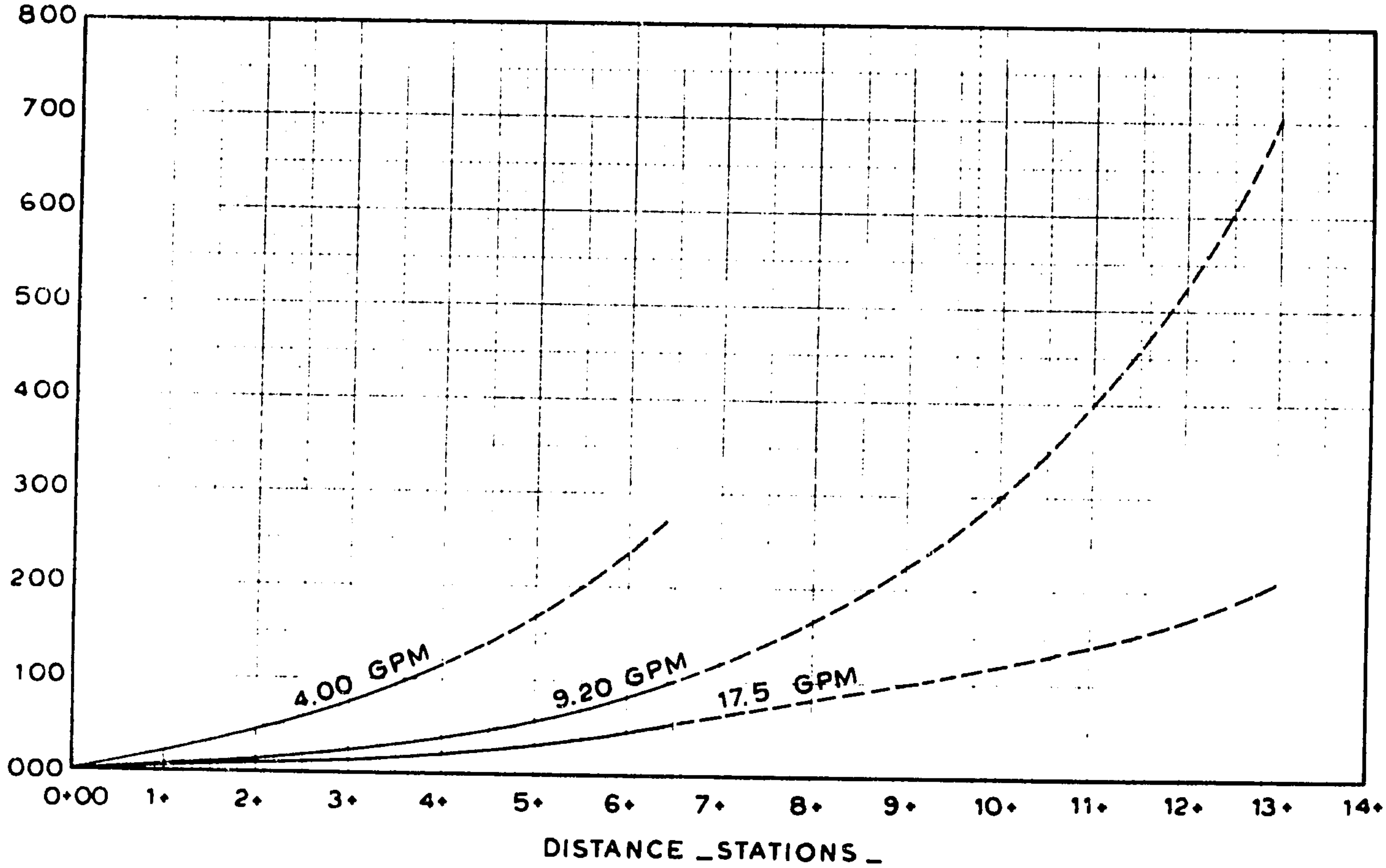


Figure IV-3. Furrow advance curves with extrapolations.

will be used here since this was close to what the irrigator was using. The ratio of the minimum depth infiltered to the average depth infiltered describes the uniformity of water intake without regard to the adequacy of irrigation. By utilizing Figures IV-2 and IV-3, and the 10-hour application, T_a, the following conditions were found: at the upper end the opportunity time, $T_{o(u)} = T_a = 10$ hours = 600 min., therefore, the depth infiltered at the upper end, $D_{(u)}$, from Figure IV-2 was 2.9 in. At the lower end the opportunity time, $T_{o(L)}$, would be $T_{o(u)}$, minus the time to advance 650 ft. to the lower end, T_{ad}, so $T_{o(L)} = T_{o(u)} - T_{ad} = 600 - 52 =$ 548 minutes. Therefore $D_{(L)}$ was 2.7 in. These relationships are shown in Figure IV-4.

$$DU = \frac{\text{minimum depth infiltered}}{\text{average depth}} \times 100$$

$$DU = \frac{2.7}{(2.7 + 2.9)/2} 100 = (2.7/2.8)\ 100 \cong 95\%$$

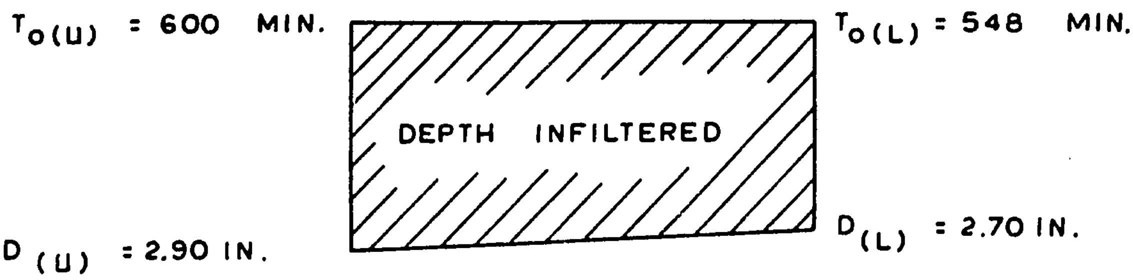


Figure IV-4. Relation of time and infiltered depth.

Potential application system Efficiency, *PE*, of the system is found when the minimum depth of water infiltered just satisfies the soil moisture deficiency. Since the irrigator was applying only about 2.7 in. when 3.6 in. was needed at that time, this efficiency must be found for the 3.6 in. condition.

From Figure IV-2, the Time of irrigation, T_i, to apply 3.6 in. is 800 minutes (13.3 hours) and will equal $T_{o(L)}$. At the upper end the water will have been on longer by the length of time it took the stream to reach the lower end, T_{ad}, therefore $T_{o(u)} = 800 + 52 = 852$ min. The average depth of water applied to the 650 ft. furrow with 3.0-foot spacing and a stream of 17.5 gpm (which is much greater than can be infiltered and therefore causes a great deal of runoff) flowing for 852 minutes (14.2 hours) is found by

$$\text{Depth Applied} = \frac{96.3 \times \text{gpm} \times \text{hours}}{\text{area}}$$

$$\text{Depth Applied} = \frac{96.3 \times 17.5 \text{ gpm} \times 14.2 \text{ hrs.}}{3 \text{ ft.} \times 650 \text{ ft.}} = 12.3 \text{ in.}$$

$$PE = (3.6/12.3)100 \cong 29\%$$

Actual application storage Efficiency, *AE*, describes how much of the water applied is retained in the soil and available for consumptive use at the point of minimum application. As this field was irrigated, the maximum depth infiltered, D(L), was 2.9 in. and did not satisfy the deficiency, i.e., all the area was under-irrigated. However, there was heavy runoff. The minimum depth infiltered (all retained in the soil) was 2.7 in. The average depth applied in the 10.0 hours was

$$\text{Depth Applied} = \frac{96.3 \times 17.5 \text{ gpm} \times 10.0 \text{ hrs.}}{3 \text{ ft.} \times 650 \text{ ft.}} = 8.7 \text{ in.}$$

$$AE = (2.7/8.7)100 \cong 31\%$$

Conclusions drawn from these computations are several. DU of 97% shows that very little more water infilters at the upper end relative to the lower end indicating that a slower rate of advance with a smaller stream would do a satisfactory job. The water reached the lower end in about 1/12 the time it was running, while 1/5 to 1/4 may be considered satisfactory, and an Advance Ratio 1/3 is often acceptable.

PE and AE were both very low, and since there was little or no loss to deep penetration, there must have been a great deal of runoff. For the system as used, runoff was 67% and if the longer time required for a full irrigation of 3.6 in. were run, it would have been even greater.

From these conclusions obvious recommendations can be made: Use a smaller stream to reach the end in about 1/4 of T_i, i.e., 13.3 hours/4 = 3.3 hours, which interpolated on Figure IV-3 would be done by a stream of about 6 gpm. Run water longer to satisfy $T_i + T_{ad} = 13.3 + 3.3$, say 17 hours; and to further reduce runoff a cut-back stream or a return flow system can be also used. In addition, it may be inferred that a much longer furrow could be used with the 17.5 gpm stream, and that an even larger stream could be used if desired and still not be erosive since Q = 10/S = 10/0.2 = 50. gpm which would permit an even longer furrow.

<u>Further evaluation</u>

By studying the cur es further, more specific recommendations can be made relative to this system and its use. These recommendations can then be considered by management for their convenience, practicability, and economics. The following is illustrative of what may be done.

Soil Moisture Deficiency at which to irrigate, MAD, must be chosen. For this soil, climate, and crop with expanding root zone, MAD may reasonably be 60%. At the time of checking, the root zone was estimated to be 3.5 ft. deep. MAD is then: 3.5 ft. (1.8 in./ft.) x 60% = 3.8 in. The estimated deficiency was 3.6 in. so that the time to irrigate was that day or the next one. Subsequent irrigations when the root zone had expanded to 5 ft. would then be applied when the MAD was about 5.0 ft. x (1.8 in./ft.) x 60% = 5.4 in. The operating procedures for these two and an earlier light application of about 2.5 in. resulting in a range for MAD from 2.5 in. to 5.4 in. requires flexibility in frequency, rate, and duration and will result in different efficiencies, desirable lengths, and durations. The system cannot easily be operated at the highest efficiency for all conditions so compromising is inevitable.

Time of irrigation, T_i, for the current 3.8 in. soil moisture deficiency is about 860 minutes. (See Figure IV-1.)

Time of advance, T_{ad}, using the one-fourth of T_i as a "desirable" relationship which will result in a very high DU, becomes 860/4 = 215 minutes. (Using an Advance Ratio as low as one-half of T_i (430 min.) may be economical, though a lower PE will result.)

Furrow length to match this desirable T_{ad} using the 17.5 gpm stream is found on Figure IV-3 to be 1320 ft. which is insignificantly longer than the 1300 ft. field. (For a smaller stream such as 9.2 gpm, the "desirable" length would be about 900 ft. For a length of 650 ft., a "desirable" stream would be about 6.0 gpm.)

Time of application, T_a, would be $T_i + T_{ad} = 860 + 215 = 1075$ minutes (18 hours).

Distribution Uniformity, DU, $= \frac{\text{minimum depth infiltered}}{\text{average depth infiltered}} \times 100.$

$$T_{o(u)} = 1075 \text{ minutes, therefore } D_{(u)} = 4.5 \text{ in.}$$

$$T_{o(L)} = T_i = 860 \text{ minutes, therefore } D_{(L)} = 3.8 \text{ in.}$$

$$DU = \left(\frac{3.8}{(3.8 + 4.5)/2}\right) \times 100 = 92\%$$

(Note that shortening the length from the "desirable" 1300 ft. to 650 ft. only increased DU from 92% to 97%.)

Potential irrigation system Efficiency, PE, when the minimum depth infiltered equals MAD, and the average depth applied on the 3 ft. x 1300 ft. furrow with no cut-back stream is

$$\text{Depth Applied} = \frac{96.3 \times 17.6 \text{ gpm} \times 18.0 \text{ hrs.}}{3 \text{ ft.} \times 1300 \text{ ft.}} = 7.8 \text{ in.}$$

then

$$PE = \frac{3.8}{7.8} \times 100 = 49\%$$

For ideal conditions of operation AE equals PE.

Water losses consist of runoff and deep percolation. The amount of runoff equals the average depth applied on the actual field length, minus the average depth infiltered. The deep percolation loss is the infiltered depth minus the stored depth. These relationships are drawn to scale on Figure IV-5.

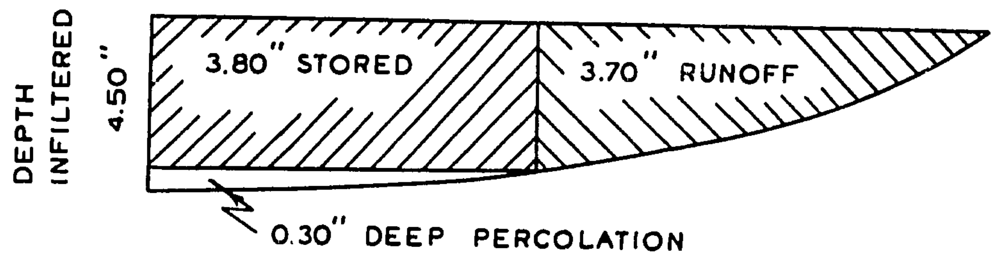


Figure IV-5. Distribution of inflow water to the furrows.

Runoff = 7.8 - (4.5 + 3.8)/2 $\cong$ 3.7 in., or (3.7/7.8)100 = 47% of that applied. This can be greatly reduced by making one or two cut-backs, or using a smaller initial stream. It can be eliminated by a return flow system which makes the water available for re-use. If the latter is done, PE will equal DU at 92% or 94%,SCS, which is a very high and attainable value within the limit that the furrow tested is typical.

Size of cut-back stream and whether only one or several cut-backs are made, depends on the economics of labor and water costs. The secondary effects of the results of runoff such as crop damage, mosquitoes, high water table, etc., will also enter into the management decision on the number of cut-backs or whether a return flow system should be installed.

The size of the infiltered stream at any moment may be found by summing the gpm infiltering in each section at that particular time. The rate of runoff is then the onflow stream minus the infiltered total. The length of the sections chosen for the following procedure must be such that rates at each end of the section do not vary greatly so that their average is representative of the section. Sections other than 100 ft. must be "weighted" since the infiltration rate is in units of gpm/100 ft.

The following study in Table IV-1 shows approximately what the stream should be cut-back to after 5 hours (300 minutes) which is about 1.5 hours after water reaches the end and is running off. 200 ft. sections will be used, except that the last one is 100 ft. T_{ad}, and $I_{gpm/100\ ft.}$ is taken from the intake rate curve.

Table IV-1. Infiltered stream at T_a = 300 minutes.

Station	T_{ad}	T_o	I_{gpm}/100 ft.	I_{av}/100 ft.	I_{av}/200 ft.
0+00	0	300	0.75	0.75	1.5
2+00	12	288	0.76	0.77	1.5
4+00	26	274	0.78	0.79	1.6
6+00	49	251	0.80	0.81	1.6
8+00	77	223	0.82	0.84	1.6
10+00	120	180	0.87	0.91	1.8
12+00	170	130	0.95	1.00	1.0/100
13+00	210	90	1.05		
					10.6

This shows that the stream should be cut back to 10.6 ± gpm from 17.5 gpm after about five hours when the runoff would be 17.5 - 10.6 = 7.0 ± gpm. By a similar process done when the irrigation is completed after 18 hours, and using the whole furrow as one section since intake rate is very uniform after this long time, it is found that the infiltration is about 7.2 gpm and runoff about 3.4 gpm at the end of the irrigation.

The average depth applied with the one cut-back would be

$$D = \frac{96.3\ (17.5\ \text{gpm} \times 5.0\ \text{hrs.} + 10.6\ \text{gpm} \times 13.0\ \text{hrs.})}{3\ \text{ft.} \times 1300\ \text{ft.}} = 5.4\ \text{in.}$$

therefore, PE = (3.8/5.4) x 100 = 71%

If two cut-backs were made the efficiency could easily be raised to better than 80% which is appreciably better than the 49% resulting from no cut-back.

Additional variations

A medium size stream, such as the 9.2 gpm, can be studied. This stream would have a slower intake rate so the second curve on Figure IV-2 would be used which gives about 15% less infiltration. (This may well be an invalid refinement since intake rates often vary much more between furrows due to cultural operations causing different compaction of the soil.)

When $D_{(L)}$ = 3.8 in. and Length = 1300 ft.

$T_i = T_{o(L)} = 1000$ min.

$T_{o(u)} = T_i + T_{ad} = T_a = 1000 + 700 = 1700$ min. = 28.3 hrs.

therefore, $D_{(u)} = 5.6$ in.

$$DU = \frac{3.8}{(3.8 + 5.6)/2} \times 100 = 81\%$$

This is an 11% reduction from the 92% given by the larger stream and shows the effect of the slower advance. The change of the Advance Ratio from 25% to 70% of T_i is of less importance than reducing waste from running water after the soil moisture deficiency has been satisfied and 100% of the onflow is wasted. Both of these wastes, deep percolation and runoff, are the responsibility of the irrigator and are not the fault of the system.

If the 9.2 gpm stream were run without any cut-back for 1700 minutes (28.3 hours)

$$D = \frac{96.3 \text{ x } 9.2 \text{ gpm x } 28.3 \text{ hrs.}}{3 \text{ ft. x } 1300 \text{ ft.}} = 6.4 \text{ in.}$$

PE = 3.8/6.4 = 60%

Note that PE for the 17.5 gpm stream was only 49% for the no cut-back condition whereas it is 60% for the 9.2 gpm stream. One cut-back would increase this to about 70% even though the furrow is 450 ft. longer than "desirable."

A 24-hour application for convenience of operation would be obtained by choosing a stream size of about 12 gpm that would take 440 minutes to advance the 1300 ft. This plus the 1000 minute T_i would give the desired duration of 1440 minutes (24 hours). This combination with no cut-back would give acceptable distribution (DU = 87%) but inefficient irrigation (PE = 54%). However, it is most convenient for labor and 24-hour duration water deliveries.

With one cut-back at 10 hours, this alternate would have a reasonable PE of about 67% and require very little labor. A return flow system would increase this to 87% and require minimum labor and only a medium size return flow capacity. The 17.5 gpm stream would give a PE of 92%, utilize the same labor, but require a larger irrigation and return flow system and cut off at 17 hours instead of 24 hours. Management must decide whether the 5% increase in PE is economical or not.

Continuous furrows save water and labor. An alternate method would be to replace the center ditch with gated pipe. In this practice water is started more or less simultaneously at the upper end and at the intermediate line or lines. Runoff from the upper portion mingles with the streams at the intermediate locations therebv utilizing the upper runoff. By cutting-back or completely turning orf the water, at the intermediate line, total runoff is reduced with a minimum of labor. With the portable gated pipe, length of run in long fields may be varied as MAD of crop changes.

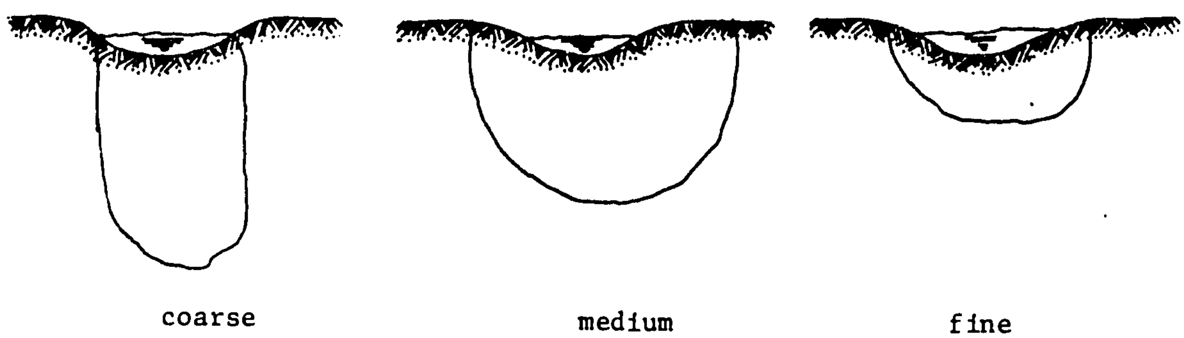
Furrow spacing and shape are important management tools to make changes in operations. Spacing is often related to crop row spacing, but there is usually a limited variation that is reasonable. A change from 30 in. spacing, for a 3.0 in. MAD, to a 36 in. spacing can be seen on Figure IV-2 to change T_i from 480 minutes to 600 minutes. This change also will permit changes in "desirable length."

If it is not practical to change spacing, the furrow could be widened by about six inches, a larger stream used and almost no change in T_i would occur.

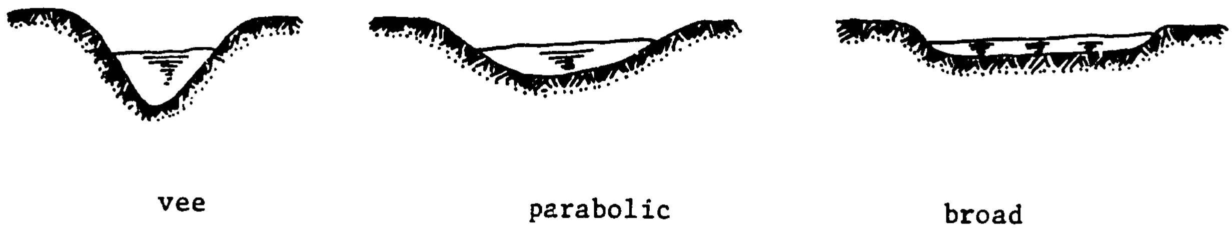
The maximum spacing for a specific furrow shape is related: 1. to the soil texture as it affects lateral capillary movement, and 2. to the soil moisture deficiency as it affects how long water runs in the furrow. A finer textured soil when dry, will move water laterally about as fast as it moves it downward. The downward speed of the moving water decreases as the wetting front meets deeper, moister soil so the intake rate decreases with time.

In coarser textures, the lateral capillary flow does not move very far, while the downward flow moves easily through the coarse soil by gravity. Finer textured soils and larger MADs permit wider spacings.

The general wetting patterns in dry soils as related to texture are as follows:



Furrow shapes can be generalized as follows:



In the vee furrow, wetted width and depth will decrease as stream flow decreases downslope. This will cause a moderate decrease in intake rate along the furrow. Parabolic and broad furrows decrease in depth with decrease in flow but have very little change in width, so intake rate is quite constant for the furrow length. Parabolic and broad furrows are capable of handling larger flows without erosion than is the vee shape, and they can easily be made different widths so they are more desirable shapes.

Sprinklers may well be used in combination with furrows to take advantage of the best features of each. Light applications are seldom practical with furrows since short furrows requiring much labor are needed to make them efficient. Sprinklers can easily, and with good efficiency, apply the light applications needed for seed germination and where crop root zones are shallow. Pre-irrigation in furrows can often be combined with the normally light germination irrigation to improve efficiency.

Summary

Present system.

L = 650 ft. Q = 17.5 gpm T_a = 10 hours

Soil moisture deficiency, smd = 3.6 in., and MAE = 3.8 in.

D_a (Depth applied) = 2.7 in. (under-irrigated)

DU = 97%

$PE_{(3.6\ in.)} = 29\%$

$AE_{(2.7\ in.)} = 32\%$ with no cut-back

There was no erosion so a larger stream and a longer furrow could be used. There was no cut-back so runoff was excessive.

Possible variations.

1. Longer furrow

$L = 1300$ ft. $\quad Q = 17.5$ gpm $\quad smd = MAD = 3.8$ in.

$T_i = 860$ min. $\quad T_{ad} = 1/4\ T_i = 215$ min. ("desirable" advance)

$T_a = T_i + T_{ad} = 860 + 215 = 1075$ min. = 18.0 hr.

DU = 94% (SCS)

$PE_{(3.8\ in.)}$ = 29% with no cut-back

PE = 71% with one cut-back

PE = 88% with two cut-backs

PE = 92% for return flow system of large capacity and no cut-back

2. Longer furrow and smaller stream

$L = 1300$ ft. $\quad Q = 9.2$ gpm $\quad smd = MAD = 3.8$ in.

$T_i = 1000$ min. $\quad T_{ad} = 700$ min. $= 7/10\ T_i$ (slow advance)

$T_a = 1700$ min. = 28.3 hr.

DU = 81%

PE = 60% with no cut-back

PE = 70% with one cut-back

PE = 81% for small capacity return flow system and no cut-back

3. Longer furrow and medium stream to obtain 24-hour duration

$L = 1300$ ft. $\quad Q = 12.0$ gpm $\quad smd = MAD = 3.8$ in.

$T_i = 1000$ min. $\quad T_{ad} = 1440 - 1000 = 440$ min. (moderate advance)

DU = 90% (SCS)

PE = 54% with no cut-back

PE = 67% with one cut-back

PE = 87% for medium capacity return flow system and no cut-back

Other alternates - the use of gated pipe to permit continuous furrows and to allow length of runs to be varied as MAD varies; the use of sprinklers for light applications in the early season, and for germination. (Many other practical alternates were not considered.)

Conclusions

A final decision by management on what irrigation practices should be followed for this field will depend on the following: the value of water in terms of its cost, or in terms of its productiveness when the supply is limited; cost and skill of labor; capital investment; secondary problems of runoff water, etc. Based on conservation irrigation alone with a high PE value, the present system of 650-foot furrows, 17.5 gpm stream, plus a return flow system putting the runoff back into a reservoir with or without a cut-back, would give an efficiency of about 97% even for a 2.5 in. application. Using the 9.2 gpm stream, PE would be 93% or greater. At other times during the season when different MAD values are desired, other stream sizes and Advance Ratios would be desirable.

Actual irrigation practices measured by AE will invariably be somewhat lower since not all furrows react exactly the same due to variations in soils and cultural practices. In addition, the value of the soil moisture deficiency determined by any practical method on a field basis is approximate, the accuracy of measuring furrow streams can seldom be high though the total depth applied is frequently adequately measured, and the convenience of labor is frequently a dominant criterion.

The ability to turn off the water when the soil moisture deficiency is satisfied is second in importance after elimination of runoff. However, furrows provide the most freedom of any method since the intake rate at the end of irrigation is the slowest rate. A 25% overrun of time may give less than 5% waste of water to deep penetration.

When the furrow length is such that T_{ad} is at "desirable" condition of about 1/4 T_i (R = 1/4), DU will be about 95%. Reducing T_{ad} has only moderate effect on improving DU. A moderate increase of T_{ad} is not greatly detrimental.

The duration of irrigation, T_i, can be modified within reasonable limits to match hours of water delivery or labor convenience by modifying the stream size (affects T_{ad} and L), MAD (affects T_i), and furrow spacing and shape (affects T_i).

Flexibility in frequency, rate and duration of supply flow are essential to obtain high irrigation efficiency and to reduce labor requirements. The stream size available in the field should be large enough to keep the irrigator busy and to start initial streams in all furrows simultaneously. The compromises between capital costs and labor and water savings must be studied. An evaluation of the irrigation system provides the basis for such study which frequently indicates a reservoir to be an economical capital investment.

CHAPTER V

BORDER-STRIP IRRIGATION

Simple Border-Strip Evaluation

A full evaluation provides information to guide management in making improvements and in understanding management techniques. However, to just determine whether a problem exists and its magnitude requires much less work and equipment.

The same basic questions relative to good irrigation operation and applicable to all methods must be asked. "Is it dry enough to start irrigating?" A soil moisture deficiency, smd, check gives the best answer, although a reasonable answer can be obtained by knowing the evapo-transpiration since the last irrigation. "Is it wet enough to stop irrigating?" This question can usually be answered by probing to check depth of infiltration at the end of irrigation. In addition, for border-strips, the water must be near the lower end of the strip by the time an adequate depth has infiltered into the upper end. This extra point is required with border-strips. If the system is being used efficienty the water should be shut off at the upper end before the flow has reached the lower end. In fact, satisyfing this final point which inter-relates stream size, soil moisture deficiency, and strip length, is the most difficult management problem with this method.

Evaluation

The short cut technique does not require measurements for the cumulative intake nor measurement of the stream flow, no special equipment other than auger, probe, and some stakes to mark distances down the strip are needed.

The simple evaluation consists of:

1. Making a soil moisture deficiency check.
2. Observing how water spreads across the strip, that no excessive high or low spots exist and that long time ponding at the lower end is not occuring.
3. Placing the stakes at uniform intervals or stations, usually 100 feet, along the length of the border.
4. Observing and recording the time when water reaches each station

so the advance curve can be plotted. Data should also be collected as the water progressively disappears, after the water is shut off, so the recession curve can be plotted.

5. Noting the time and location of the water front when the inflow is turned off.

6. Observing the magnitude of runoff. Duration of the runoff is recorded by the information obtained in step 4.

7. Checking with the probe as the water recedes down the strip to determine the adequacy and uniformity of infiltration. An additional simple check on irrigation adequacy can be made by calculating the depth of application if the flow rate, irrigation duration, border length and border width are known.

Analysis

The objective of evaluation is to determine how effectively the land, water and labor are being used within the framework of other management considerations.

The obvious problems can be demonstrated by utilizing the easily obtained portion of the data and observations from the full evaluation in the following section. For ease of discussion, the seven steps listed under Simple Evaluation will be followed in the analysis of an irrigated alfalfa assuming a MAD of 50% which is a very widely accepted condition to good growth.

1. The soil moisture deficiency check showed the top soil was quite moist, which is an indication that the MAD was still well above 50%. For a MAD of 50% the smd is : 50% x (6.0 ft. x 1.5 in./ft.) = 4.5 in. The full root zone depth soil moisture deficiency check indicated there was plenty of moisture all the way down and that the smd only amounted to 2.9 inches. Although irrigation could have been delayed a few days; applications were made to fit the harvesting operations. To accomplish this, lighter irrigations on a shorter strip at more frequent intervals than required for a MAD of 50% are needed.

2. Observing the water flow showed that the land grading was good since there were no dry spots or ponds.

3-5. The simply obtained time and distance relationships of the point when water disappeared at each station along the strip are plotted as shown in Figure V-1. The time at which the water was turned off

(88 minutes) and where the water front was at that time (at 600 ft) are also plotted. Comparing Figure V-1 which indicates the advance and recession curves converging with the combined curves shown in Appendix F. it can be seen that the stream is too small. The water front at cutoff was very close to the end of the upper half of the strip and there was quite a bit of runoff into the lower half, therefore, the cutoff was too late for this length of field. There is no indication from Figure V-1 as to the adequacy of irrigation.

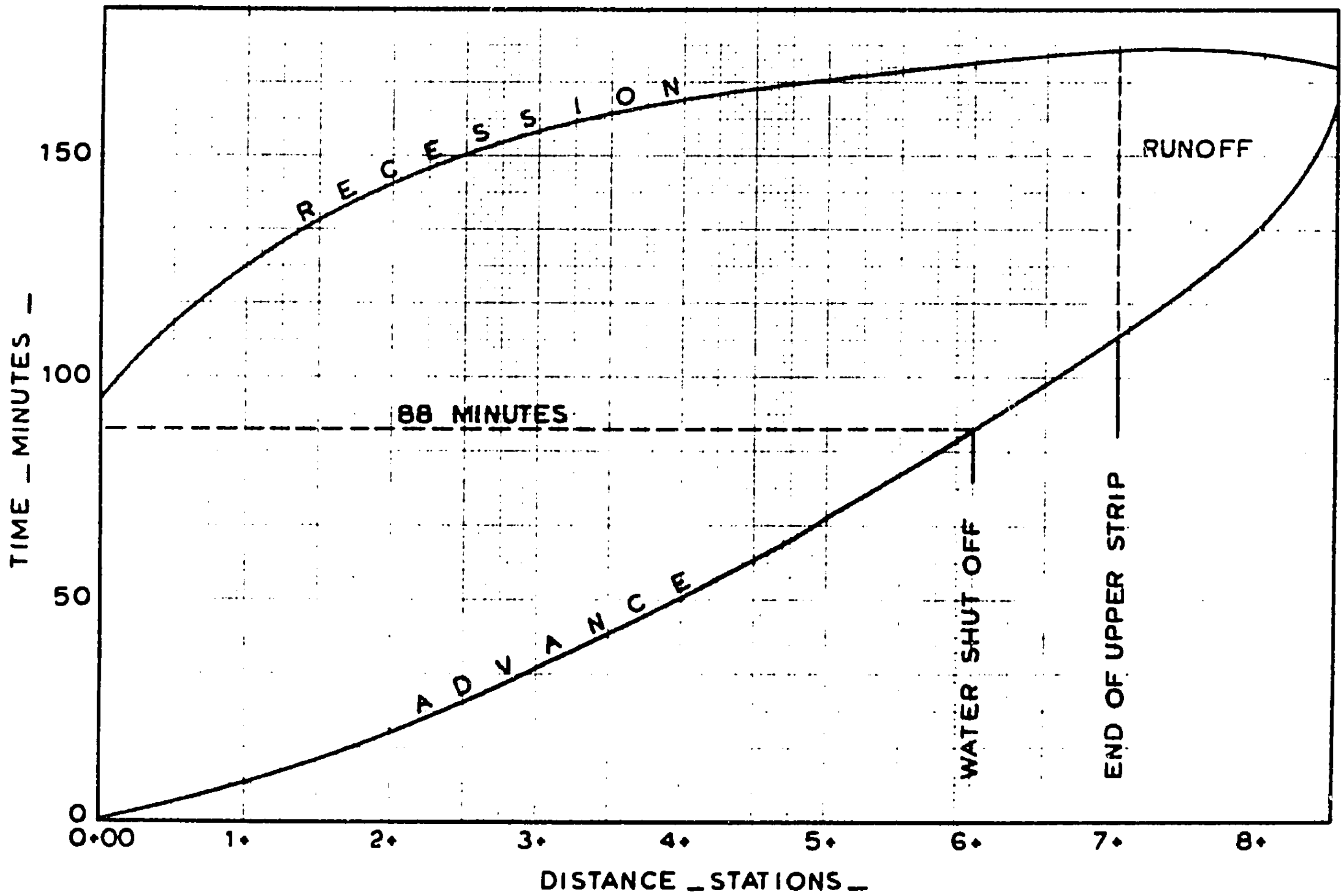


Figure V-1. Advance and recession curves used in simple evaluation of border-strip.

6. The runoff stream was of fair size and as seen from the time interval between the advance and recession curves at station 7 + 00, at the end of the upper strip, it lasted for about 65 minutes. It is necessary that water at the end either be ponded or running off for as long as needed to

replace the soil moisture deficiency but 65 minutes seems too long since the smd only equals 2.9 in.

7. The adequacy of the penetration at the lower end was not checked with the probe or auger as it should have been. So, for this evaluation it can only be surmised that an adequate depth had infiltered. An auger check in an adjacent previously irrigated strip showed that it had at least enough.

It is helpful but not essential to know the flow rate. For this border strip the flow rate was the full flow of the well which was reported to be 1.2 cfs. The borders were spaced 24 feet but only 23 ft. were wet and the length was 700 feet long which is 0.37 acre flow occurred for 88 minutes. Using the simple relationship, 1.0 cfs x 1.0 hr. = 1.0 acre-inch, the depth applied to the strip can be computed by

$$\text{Depth Applied} \fallingdotseq \frac{1.2 \text{ cfs} \times \frac{88}{60} \text{ hrs.}}{0.37 \text{ ac.}} = 4.8 \text{ inches}$$

Knowing the depth applied, the Actual application storage Efficiency can be found

$$AE = \frac{2.9 \text{ in.}}{5.2 \text{ in.}} \times 100 = 60\%$$

Recommendations

1. Delay irrigation a few days until the soil becomes drier, of if the harvest of a green-crop requires an early irrigation, a lighter irrigation may be applied which probably would require a shorter strip for good efficiency. (See Appendix F).

2. Use a larger stream to advance more quickly so that the advance and recession curves plot nearly parallel indicating a uniform infiltration opportunity.

3. Cutoff the stream before the water front was so near the end in order to reduce runoff, but not so soon as to under-irrigate the lower end.

Summary

The field was being irrigated sooner than necessary as far as the smd was concerned. The grading of the field was satisfactory. The uniformity of the depth infiltered was not very good but it could be easily improved by a larger stream. The cutoff was made too late which resulted in excessive runoff which could be reduced by cutting off flow sooner. The adequacy of irrigation was believed good from a check on an adjacent strip. The AE of about 60% was low, but the larger stream to make application more uniform, and cutting off sooner to reduce runoff would improve the efficiency.

Full Border-Strip Evaluation

The border strip method of irrigation can be one of the most efficient methods, however it involves more irrigation management skill than any other method since several factors must be simultaneously coordinated or compromised. A study of the procedures is essential to proper operation and understanding of the complexities, such as the facts that strips should have a specific length for a specific irrigation, that short strips may be impractical, that water is normally turned off before it reaches the lower end, that the upper end of the strip may be under-irrigated relative to the lower end or middle in contrast to furrows which always over-irrigate the upper end. A number of illustrative advance-recession curves are shown in Appendix F to help in interpreting field conditions.

Border-strips are of two types based on the intensity of land preparation. This is related to whether the soil profile is such that cuts and fills can be tolerated, and to the economics of land preparation. Graded border-strip irrigation involves preparing the ground to give uniform slopes down the strip and be level, or nearly so, across the strip to assure uniform water coverage. This must be done with full consideration of variable soil intake rates to obtain uniform infiltration. The basic objective in land grading is not to get a uniform grade, but is to obtain uniform irrigation. Guided border-strips are constructed down the steepest grade which permits them to be nearly level across naturally or with very little grading. Grade and soil variations along such strips are tolerated to reduce the amount of grading. The strips are frequently quite narrow to assure the water spreading over the entire width.

Evaluation

Both types are evaluated the same way. A typical location in the field is chosen at a time when an irrigation should be done, and information is obtained about 1. the flow rate and duration of the various size streams turned into several border-strips, 2. the rate of advance of the streams down the strips, 3. the time of recession of the water from the surface at each station, 4. the cumulative intake depth of water into the soil with time, 5. the width of the wetted portion of strips, 6. the soil moisture deficiency, 7. the adequacy of the irrigation a day or so later.

Additional information for more detailed study is desirable such as 1. profile and cross slope of the strips, 2. soil texture and profile, 3. depth of water at upper end and along the strip at different times, 4. rate and duration of runoff at lower end, and 5. the stage of growth of the crop and its affect on retardance of flow.

When the field data has been plotted, a study of it will quickly show the 1. Distribution Uniformity, 2. the Potential irrigation system efficiency, 3. Actual application storage Efficiency, 4. duration of Irrigation, and 5. Correct stream size.

A more complete study will show how variations in stream size, field length, soil moisture deficiency, smd, and time of cut off can be varied to Potential irrigation System Efficiency.

Equipment needed

1. Surveying tape to locate stations.
2. Lath or stakes to mark stations, and a hatchet to drive them.
3. Ordinary watch.
4. Flow measuring devices such as Parshall flumes, large siphons, weirs, flow meters, horizontal pipe jet, or others which may be improvised, and time or head measuring device needed. (See Appendix C.)
5. Shovel.
6. Soil auger.
7. Soil prove.
8. Infiltrometer (usually 5 cylinders), buckets, and measuring guage.
9. Forms for recording data.
10. Surveying level and rod.
11. Soil moisture deficiency measuring equipment.

Field procedure

1. A location should be chosen such that the soil, slope, crop, etc., are representative of the field. A steady source of water should be available.

2. Select three strips which may be adjacent to each other, or preferably alternates to avoid walking on wet soil.

3. A minimum of six set stakes adjacent to a border, usually at 100-foot intervals and measure wetted strip width and border spacing.

4. Set a flow measuring device at the inlet of each strip. Another one may also be set at the lower end to record runoff if it is likely to occur.

5. Determine soil moisture deficiency and compare it with the desired deficiency, MAD. (See Appendix A.) If it is appreciably different, the evaluation will be noticeably affected as intake and advance rates are affected by the moisture content of the soil.

6. Set four or more cylinder infiltrometers in a carefully chosen typical location. (See Appendix E.)

7. Set a constant rate stream of the usual size and also a larger and a smaller stream in the selected strips. Record their flow rates. Check the rates for consistancy during the test. Record the time flow was started and shut off, and any variations. Water is usually shut off when the stream has advanced about 0.7 to 0.9 of the strip length for fine and coarse textured soils respectively.

8. Record the time the stream reaches each station. If the moving stream front is irregular, use an average front.

9. Measure, or observe and describe, the runoff rate at several times. The beginning and end of runoff can be readily observed from the advance and recession curves.

10. Record the time the water disappears at each station. This may be difficult due to puddles and small channels, or sod in pastures. The objective is to determine when the water no longer has an opportunity to infiltrate most of the soil. Consistency in choosing the condition at all statons is important. The recession curve resulting from this data is the key control in the evaluation procedure. There will be an appreciable lag in time, T_L, at the upper end after the water is turned off before the water recedes at this location.

11. The adequcy of the irrigation should be checked a day or so after irrigation using a soil auger or tube. During irrigation the penetration of the water can be determined to depth of about three feet by using a probe.

Additional information may be obtained for a more detailed study and to assist in designing other systems, and may consist of:

12. Detailed soil texture and profile.

13. Elevations at the stations to determine gradient.

Utilization of field data

Graphical presentation facilitates the analysis of the field data.

The cumulative intake curve for each infiltrometer is plotted on a sheet of 3-cycle full logarithmic paper. These usually are straight lines, but may curve slightly, or may "dogleg." Curves for sands often steepen after a few minutes due to the release of air trapped by the water covering the surface. This permits water to enter more rapidly. Cylinder infiltrometers which are not driven deeply enough may also show steepened curves. Soils which have openings into which the water goes quickly often yield curves which are steep for a few minutes, then flatten. Plow pans will have a similar but delayed effect. The data from the cylinders should not be averaged before plotting as the correct slope of the line will be affected and the various soil conditions and range of intakes masked. The zero and half-minute readings are not usually plotted on the log-log paper, but are valuable in checking unusual conditions. After all lines are plotted and deviations considered and allowed for, a "typical; line can be drawn for use in evaluation. Its position can be checked later and adjusted as necessary in order to give the correct duration for irrigation.

The advance and recession curves for each test are plotted on coordinate paper. A separate sheet is used for each strip. The strip identification, width, stream size, soil moisture deficiency, soil texture, crop, retardance description, slope and any other pertinent information that may have been obtained, should be noted on each sheet. It is preferable to plot the data as it is recorded. Watch time instead of accumulative time may be used. These curves are plotted on Figure V-3 from data on Form V-2.

FORM V-1. CYLINDER INFILTROMETER DATA SHEET

Location *G. Ranch, Santa Maria* observer *JLM* date *16 Aug 71*

Soil symbol *IL 56* soil texture *s.l.* soil moisture *2.9"/5' moist*

Crop history *alfalfa green chop. Equipment traffic in middle*

Remarks *soil not dry enough to warrant irrigation. Cylinder #4 refilled*

CYLINDER 1

TIME watch	TIME diff	TIME cumu	INFILTRATION depth	INFILTRATION diff	INFILTRATION cumu
10:55		0	2.50		0
56	1	1	.60	.10	.10
59	3	4	.80	.20	.30
11:01	2	6	.85	.05	.35
05	4	10	3.00	.15	.50
17	12	22	.30	.30	.80
26	9	31	.45	.15	.95
38	12	43	.60	.15	1.10
12:03	25	68	4.00	.40	1.50
21	18	86	.10	.10	1.60
39	18	104	.35	.25	1.85
1:20	41	145	.80	.45	2.30
58	38	183	5.30	.50	2.80

CYLINDER 2

TIME watch	TIME diff	TIME cumu	INFILTRATION depth	INFILTRATION diff	INFILTRATION cumu
10:57		0	1.70		0
:58	1	1	.90	.20	.20
11:06	8	9	2.40	.50	.70
18	12	21	.70	.30	1.00
27	9	30	.90	.20	1.20
49	22	52	3.40	.50	1.70
12:13	24	76	.85	.45	2.15
31	18	94	4.15	.30	2.45
49	18	112	.50	.35	2.80
1:30	41	153	5.15	.65	3.45
2:08	38	191	.95	.80	4.25

CYLINDER 3

TIME watch	TIME diff	TIME cumu	INFILTRATION depth	INFILTRATION diff	INFILTRATION cumu
10:59		0	2.20		0
11:00	1	1	.50	.30	.30
02	2	3	.60	.10	.40
07	5	8	.70	.10	.50
18	11	19	.90	.20	.70
27	9	28	3.00	.10	.80
49	22	50	.25	.25	1.05
12:14	25	75	.50	.25	1.30
50	36	111	.95	.45	1.75
1:30	40	151	4.35	.40	2.15
2:08	38	189	.80	.45	2.60

CYLINDER 4

TIME watch	TIME diff	TIME cumu	INFILTRATION depth	INFILTRATION diff	INFILTRATION cumu
11:03		0	1.40		0
04	1	1	2.00	.60	.60
08	4	5	.25	.25	.85
18	10	15	.70	.45	1.30
27	9	24	.90	.20	1.50
49	22	46	3.35	.45	1.95
12:14	25	71	.95	.60	2.55
50	36	107	4.60	.65	3.20
1:30	40	147	5.50	.90	4.10
2:08	38	185	6.30	.80	4.90
08	-0-	185	2.15	-0-	-0-
36	28	213	2.65	.50	5.40

CYLINDER ____

TIME watch	TIME diff	TIME cumu	INFILTRATION depth	INFILTRATION diff	INFILTRATION cumu

CYLINDER ____

TIME watch	TIME diff	TIME cumu	INFILTRATION depth	INFILTRATION diff	INFILTRATION cumu

FORM V-2. WATER ADVANCE and/or RECESSION DATA SHEET

Location C. Ranch, Santa Maria Date 8/16/71 Soil Texture sl Moisture Deficiency 2.9"/5' Crop alfalfa

Comments mowed recently for green chop. 6" Parshall, depth .55'. 24' border with 21' strip Observer JLM

Adv. or Rec.	Adv.	Rec.		
Identification				
Stream Size	1.20 cfs			

TIME			Station
watch	diff.	cumu.	feet
10:51		0	0+00
10:59	8	8	1
11:12	13	21	2
26	14	35	3
41	15	50	4
59	18	68	5
12:18	19	87	6
40	22	109	7
13:06	26	135	8
32	26	161	8+50

TIME			Station
watch	diff.	cumu.	feet
10:51		0	0+00
off 12:19	88	88	0
12:27	8	96	0+00
59	32	128	1
13:18	19	147	2
29	11	158	3
33	4	162	4
38	5	167	5
41	3	170	6
45	4	174	7
43	-2	172	8
42	-1	171	8+50

TIME			Station
watch	diff.	cumu.	feet

Rod reading	Station feet
3.70	0+00
4.55	1
4.75	2
5.00	3
5.50	4
6.00	5
6.48	6
7.00	7
7.50	8+00

Note – For border-strip recession data, first time entry should be made when water started, second entry at time water turned off, third entry when recession starts, and all these entries should be at station 0 + 00.

Analysis

The following example illustrates an analysis to determine the uniformity of the irrigation, the potential efficiency of the system, and how to improve its use. Only one strip was used because water came from a well and was invariable in rate and small in size.

The strip tested was in the upper half of a 1400-foot long field with a supplemental pipe line at 700 ft. Water running beyond the midpoint would normally be considered runoff unless the supplemental line and upper line were utilized simultaneously to irrigate the 1400-foot length as a continuous strip. (In fields where the strip terminates at the end of the field, the advance and recession curves may be extrapolated to their intersection to graphically portray the runoff. This extrapolation can be simulated for a strip by cutting off the flow sooner. For this test the actual curves are plotted beyond station 7+00.)

Cumulative intake curves plotted on Figure V-2 from data on Form V-1, show the infiltration from the four cylinders. One resulted in a straight line, two "dogleg" appreciably, and another only slightly. Anticipating the effect of a rapid initial intake, but using the slope of the consistent portion of the lines, a straight line, presumed to be "typical" of all, was drawn and labeled. As described below, an "adjusted" line was later drawn and used for the evaluation process since it averages the intake rate of the shown field and therefore is more representative than the cylinders data. Note that averaging the data to plot only one line would be misleading and it would not indicate the range of conditions that actually exist.

Adjusted Cumulative Intake is developed as shown on Figure V-3 and Figure V-4. At each station on the total strip (actual and extrapolated portions) the time water was on the ground, T_o, was noted. This was done by measuring the time interval between the advance and recession curves. The corresponding depth infiltrated was taken from the Cumulative Intake Curve (typical) and note on Figure V-4 for the same station. The average depth for each 100 ft. was determined and since the end position of the field was less than 100 ft. Its average depth was determined proportionally to its length. The average depth infiltrated for the entire strip (extrapolated) was then found to be $d = 25.0/8.5 = 3.0$ in.

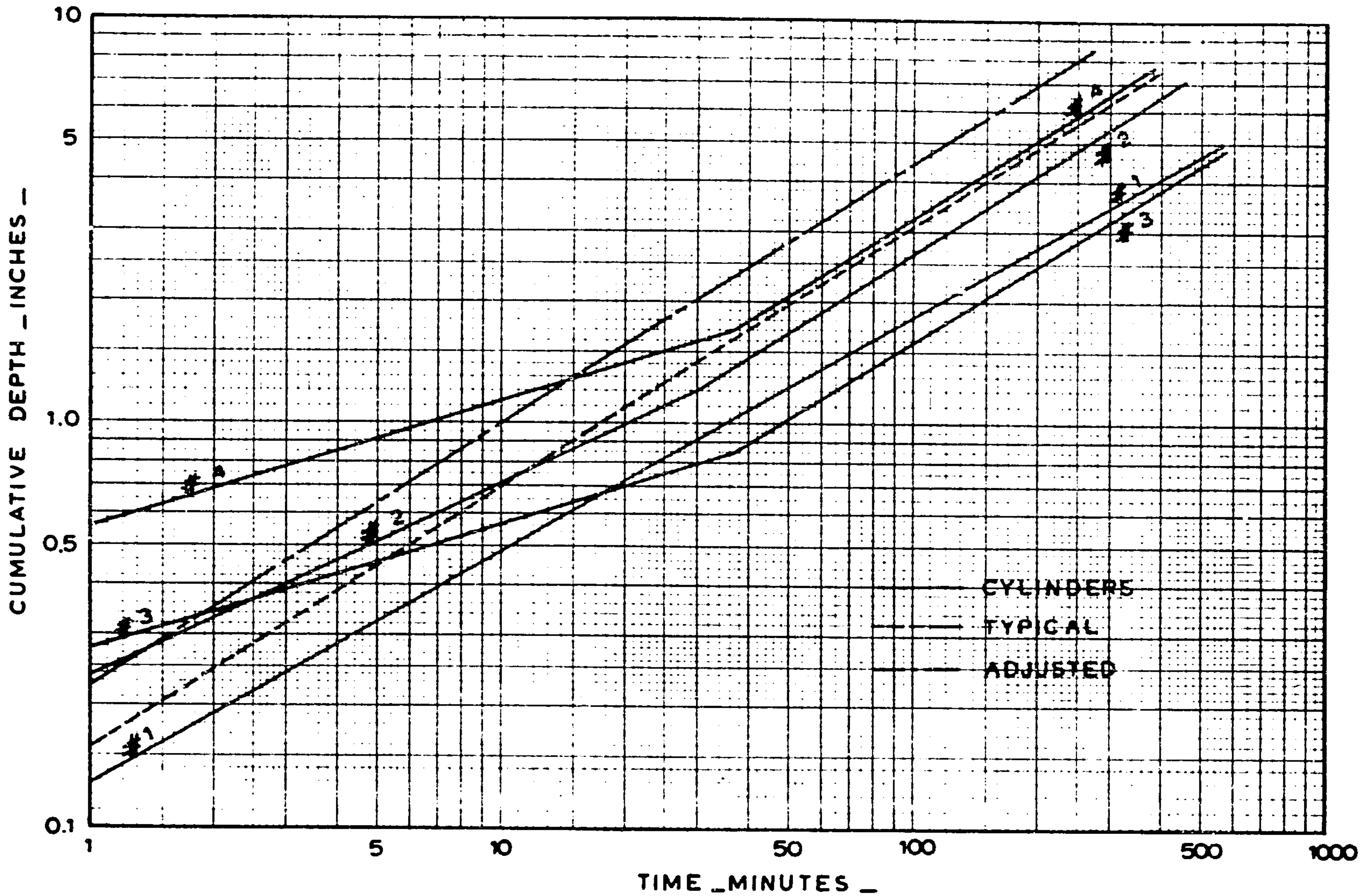


Figure V-2. Cumulative cylinder intake curves.

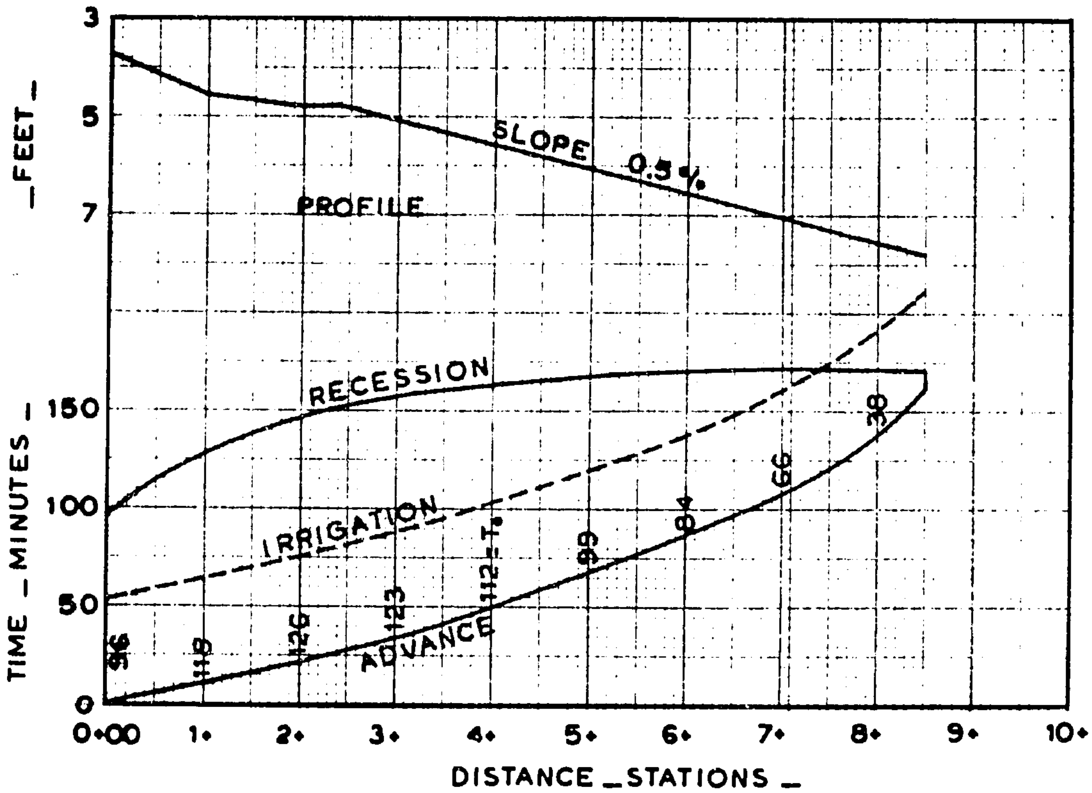


Figure V-3. Advance, recession and irrigation curves for border-strip irrigation evaluation.

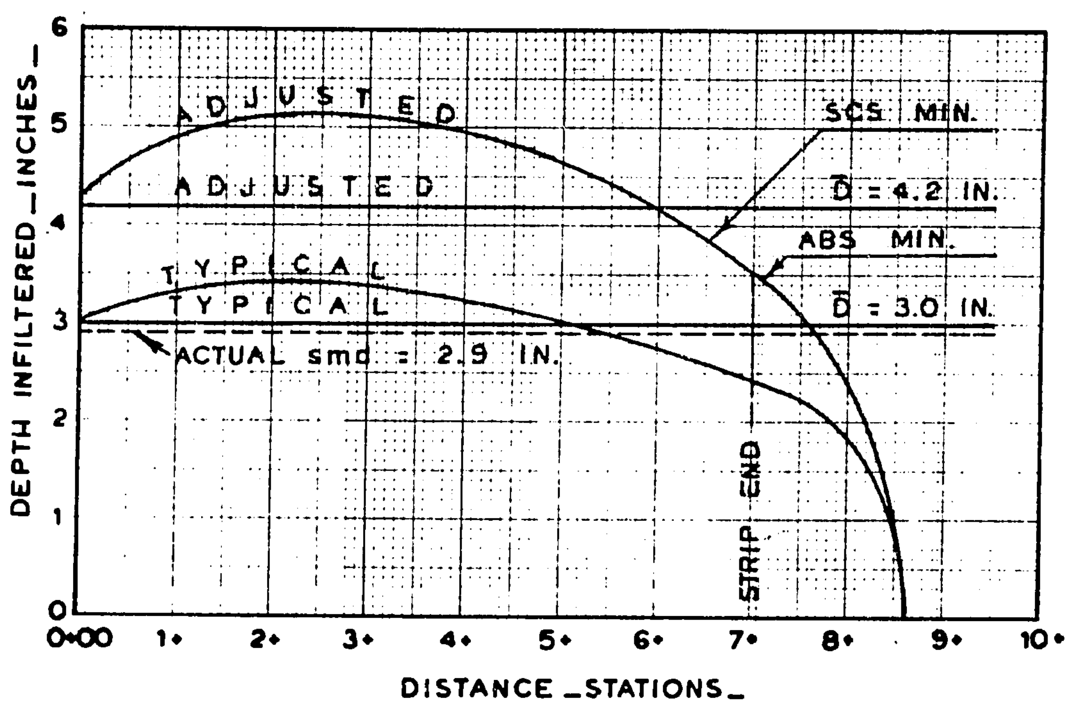


Figure V-4. Typical and adjusted depth of infiltration.

<u>Depth Infiltered from TYPICAL INTAKE. Figure V - 2,3</u>

Sta.	0+	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+
To	96	118	126	123	112	99	84	66	38	10	
D	3.0	3.4	3.5	3.5	3.3	3.0	2.8	2.4	1.7	0.7	
D/100'	3.2	3.5	3.5	3.4	3.2	2.9	2.6	2.1	1.2/2		

Av. depth, D, on 850' 25.0'/8.5 = 3.0" (plotted on Figure V-2)

<u>Depth Infiltered from ADJUSTED INTAKE. Figure V - 2,3</u>

Sta.	0+	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+
D	4.3	4.9	5.1	5.0	4.8	4.4	4.0	4.0	3.4	2.4	1.0
D/100'	4.6	5.0	5.0	4.9	4.6	4.2	3.7	2.9	1.7/2		

To check the correctness of the location at which the "typical" curve was drawn, the actual average depth of water applied was computed using the relationship 1.0 cfs x 1.0 hr. = 1.0 ac-in.

$$d = 1.20 \text{ cfs} \times \frac{88}{60} \text{ hr.}/(\frac{23 \text{ ft.} \times 850 \text{ ft.}}{43560} \text{ ac}) = 3.9 \text{ in.}$$

The adjusted line was drawn on Figure V-2 through a depth of 3.9 in. at the time the typical average depth of 3.0 in. occurred, i.e., 96 minutes.

As a check, and since the values will be used later, the adjusted depths at each station, the average depths between stations, and the average for the whole length (extrapolated) was found again using the adjusted curve, d = 32.5 in./8.5 = 3.8 in. This is also shown graphically on Figure V-4. This adequately checks the 3.9 in. computed onflow depth and proves that the "adjusted" curve is reasonably correct.

Distribution Uniformity, DU, the ratio of the minimum depth infiltrated to the average depth infiltrated, describes how uniformly the water is distributed along the strip for the condition tested. A high ratio indicates that the advance and recession curves are "parallel." It does not tell whether the irrigation was adequate or not. For this ratio, which is concerned only with the infiltrated water, runoff is not pertinent and therefore, only the actual field length is used. The infiltrated average for the 700 ft. was found as before from Figure V-4, d = 29.2/7.00 = 4.2 in.

The minimum depth can be defined as the Absolute minimum 3.2 in. occurring at station 7+00, or as the SCS minimum, which is the average depth of the lowest one-quarter or 3.7 in. for the last 175 ft. in this test. These are shown graphically on Figure V-4.

Absolute DU =(3.2/4.2)x 100 = 76%

SCS DU =(3.7/4.2)x 100 = 89%

Potential irrigation system Efficiency, PE, the percent ratio of the minimum depth when it just equals the MAD or the soil moisture deficiency to the average depth applied, describes how well the system can operate using the tested condition. Referring to Figure V-4, the minimum (Absolute) occurs at station 7+00 and is 3.7 in. The SCS minimum is 3.7 in. The average depth of the total water applied on the 700-foot long field, including the portion that runs off, is 32.5 in./7.00 = 4.6 in. So if MAD were equal to the minimum, PE would be

Absolute PE =(3.2 in./4.6)x 100 = 70%

SCS PE =(3.7 in./4.6)x 100 = 80%

It is convenient for study of an evaluation to use the Absolute value of minimum, but any comparison with another test or method must be done using the SCS minimum to make valid comparisons.

Actual application storage Efficiency, AE, the percent ratio of the minimum depth of zone to the average depth applied, tells how well the system is being used. To visually present the adequacy of irrigation, the irrigation curve is plotted on the same plot as the advance-recession (Figure V-3). Also the depth of the soil moisture deficiency, assuming it will equal the stored depth, may be plotted on Figure V-4. The irrigation curve is plotted above the advance curve equal to the time needed to infilter an adequate irrigation, T_i. If the irrigation line is below the recession, water is on too long a time and over-irrigation is indicated. When it is above the recession, the area is under-irrigated. On the depth curves, the excess or deficiency is shown in depth rather than in time.

At the time of irrigation the soil was slightly moist as the owner made it a practice to irrigate immediately after cutting the alfalfa for green-chop feed without any knowledge of the soil moisture deficiency. The deficiency was found by utilizing the soil moisture and appearance relationship chart in Appendix A. Soil auger samples were taken representing each foot increment of the sandy loam soil to a depth of five feet. The soil moisture deficiencies were estimated to be 1.0, 0.8, 0.6, 0.4, and 0.1 in. for a total of 2.9 in. This deficiency equals all of the available storage so

2.9 in. can be used as the depth stored and plotted on Figure V-4. The time to infiltrate the 2.9 in. is 60 minutes which is plotted as an irrigation curve on Figure V-3.

$$AE = (2.9 \text{ in.}/4.6) \times 100 = 63\%$$

This is about 7% less than it would have been if he waited a couple of days and the soil moisture deficiency became about 3.2 in. The AE would have equalled PE, 70%. This illustrates the management controllable effect of changing MAD to save water and also labor.

The correct time of irrigation, T_i, to meet the 2.9 in. deficient is observed from the "Adjusted" curve of Figure V-2 to be 60 minutes. This must be considered only as an approximate time since many variables exist. For the 66 minutes water actually infiltrated at the lower end the corresponding MAD is 3.2 in.

The best stream size, Q, could not be found from this test since the entire flow of the well was used and no larger stream could be applied. It is obvious, from the fact that the recession and advance curves converge (see Appendix F), that the stream size is too small and a larger stream would advance more rapidly. This would tend to make the advance and recession curves nearly parrallel representing a more uniform irrigation, permitting earlier cut-off, and reducing over-irrigation on the upper portion of the strip.

For the field evaluated, a larger stream could be obtained by utilizing a reservoir, or at the time the field is re-planted, the width of the strip could be reduced to increase the flow rate per foot of width.

Adequacy of irrigation was checked on the adjacent strip irrigated similarly the previous day. The soil was at or above field capacity to a depth of five feet. This confirmed the over-irrigation indicated by the evaluation.

Summary of basic analysis

Utilizing only the information obtained and studied, the following was determined: that irrigation was being applied too soon to match the capability of the system as it was being operated; that DU at 76% could be improved by using a larger stream which would advance more rapidly; that PE at 70% (SCS at 80%) could be improved by using a larger stream and larger MAD; that AE could be made equal to PE at 70% simply by delaying irrigation a couple of days, and that increasing the stream size would improve all conditions. It must be remembered that none of the values is exact, but that all are very significant in indicating what should be done. Additional analysis will tell in detail what procedure should be followed and its effect so that an economic comparison can be made.

Additional analysis

In addition to the basic evaluation, more study and some additional information will provide the basis for more detailed recommendations. Alternates may be developed and economic comparisons made.

With the shape, but not the starting time, of the recession curve relatively unchangable, the three fundamental aspects that management can control and adjust to improve border-strip irrigation are: 1. stream size which affects rate of advance and duration, 2. the soil moisture deficiency at which the crop is irrigated, MAD, as it affects duration and frequency, and 3. the distance to the point of cut-off and the length of the strip which can be sometimes varied by use of portable pipe. Other factors such as having uniform soil and land grading may be of great importance. They are more difficult to change but may be considered on new fields.

Observation of the advance, recession and irrigation curves plotted on Figure V-3, identified several problems: too small a stream, over-irrigation for entire length, and an unnecessarily low MAD. An additional noticeable condition is the abnormal hump, rather than the typical S curve, in the recession curve at the beginning, and the change in slope of the advance curve at about station 1+00.

Advance and recession curves that are abnormal indicate changes from uniform conditions in retardance, slope, or intake rate (See Appendix F). The steep beginning 200-foot portion of the recession curves on Figure V-3, indicating slow run-off, was not caused by increased retardance since the crop was uniform, but could have been caused by a flatter grade or reduced intake rate. The flatter beginning 100-foot portion of the advance curve, indicating rapid advance, was not caused by reduced retardance, but could have been caused by a steeper grade or reduced intake. The only influencing factor common to both advance and recession was reduced intake. If sharper scrutiny were not taken, this would be assigned as the reason. However, by observing that the reduced recession was effective on about two hundred feet and increased advance affected only about one hundred feet, further explanation was needed. The plot of the ground profile on Figure V-3 (using rod readings as being easier than elevation) showed that the cause was really made up of two changes in grade, steep for about 100 ft., then flatter. These grades are quite adequate to explain the shape of both curves. Intake rate probably was uniform. The recession curve probably would have started flatter and been indicative of the true problem if an advance and recession reading had been made at station 0+50. It may safely be surmised that if the upper part of the field were brought back to grade the relative steepness of the hump in the upper 100 foot portion of the recession curve would be reduced by increasing the lag time, to give the normal S shaped curve. Also, the advance curve would become a uniformly smooth curve. Such curves could be estimated, assuming the grades were corrected, efficiencies computed, and an economic study made of regrading. The major effect would be on time of lag, T_L, and probably would be of little economic value. However, it does illustrate the diagnostic capabilities of studying the curves.

Stream size was indicated to be too small by the convergence of the advance with the recession curve. The fundamental control condition in adjusting stream size is that the general shape of the recession curve does not change appreciably in shape or slope except under rather extreme changes in irrigation practices. The last of the water to disappear is doing so at about the same intake rate and flow velocity each time unless large changes in duration are made. The ground slope remains constant, though the retardance may vary. As stream size changes, the time of lag may vary. especially on flat gradients and slow intake soils. However, the general shape of the recession curve is fixed as shown on Figure V-5 which illustrates three stream sizes from another test. A larger stream should also have been run.

The recession curve for the large stream shows the typical S recession. A dike at the lower end ponds the water. The dotted lines show the extrapolated curves that might have occurred if there had been no dike and runoff had happened. The recession for the medium stream and distance shows the S shape but is flatter (faster recession) at the lower end due to less water moving ahead from the shorter and shallower body of water ponded upstream. The smallest stream, with the pronounced drop down, emphasizes the extreme results of a much too small stream.

For the evaluation being studied, during which only one stream size could be run, and it was too small, the question is how much larger it should become. The evaluation procedure can provide an approximate answer.

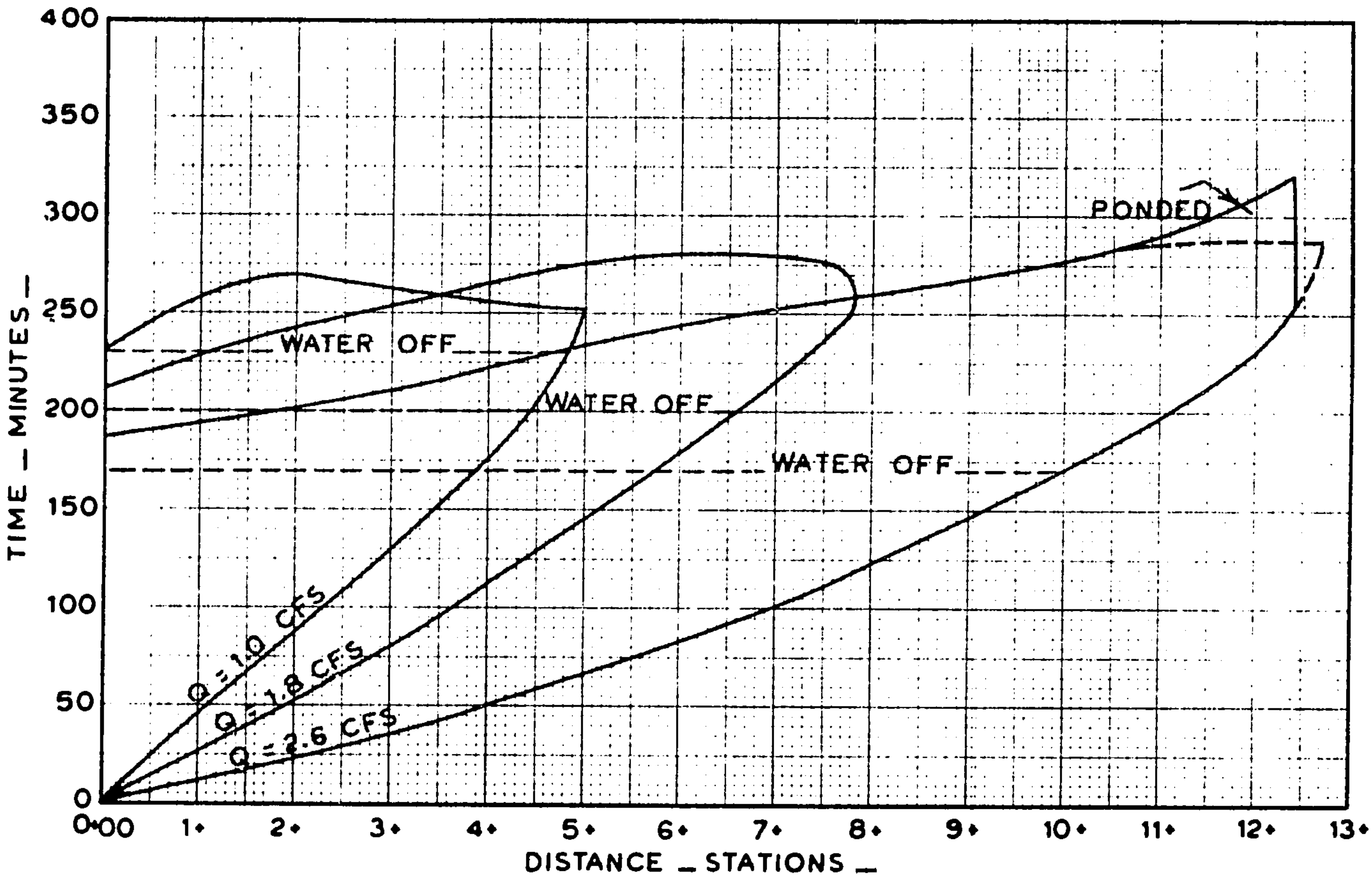


Figure V-5. Advance - recession curves for several streams.

Proper stream size use will create several conditions. These conditions which should be met for an efficient irrigation are: beginning of recession equals time of irrigation, i.e., at the upper end $T_o = T_i = T_a + T_L$; that at all points the irrigation curve be below the recession curve; and also at the time of cut-off of flow, T_a, that the stream is far enough advanced down the strip that there is adequate water in storage to flow to and irrigate the far end. It is rare in practice that all three conditions can simultaneously be satisfied.

Figure V-6 shows the desired conditions for a MAD of 2.9 in.: the recession curve starts at 60 minutes, T_i, and is drawn in the shape found from the field evaluation; at station 7+00 a point is located for the advance curve 60 minutes below the recession to ensure an adequate irrigation there; an advance curve is plotted in shape similar to the tested shape but flatter to represent a larger stream; a time of lag, T_L, is estimated to be about 10 to 12 minutes since the stream will be larger than 1.2 cfs which had a lag time of 8 minutes; time of cut-off, T_a, is then 54 - 12 = 42 minutes; the distance down the field at this time is about 530 ft. This may be about correct since it is 270 ft. from the extrapolated end and the original 1.2 cfs went 260 ft. after shut-off.

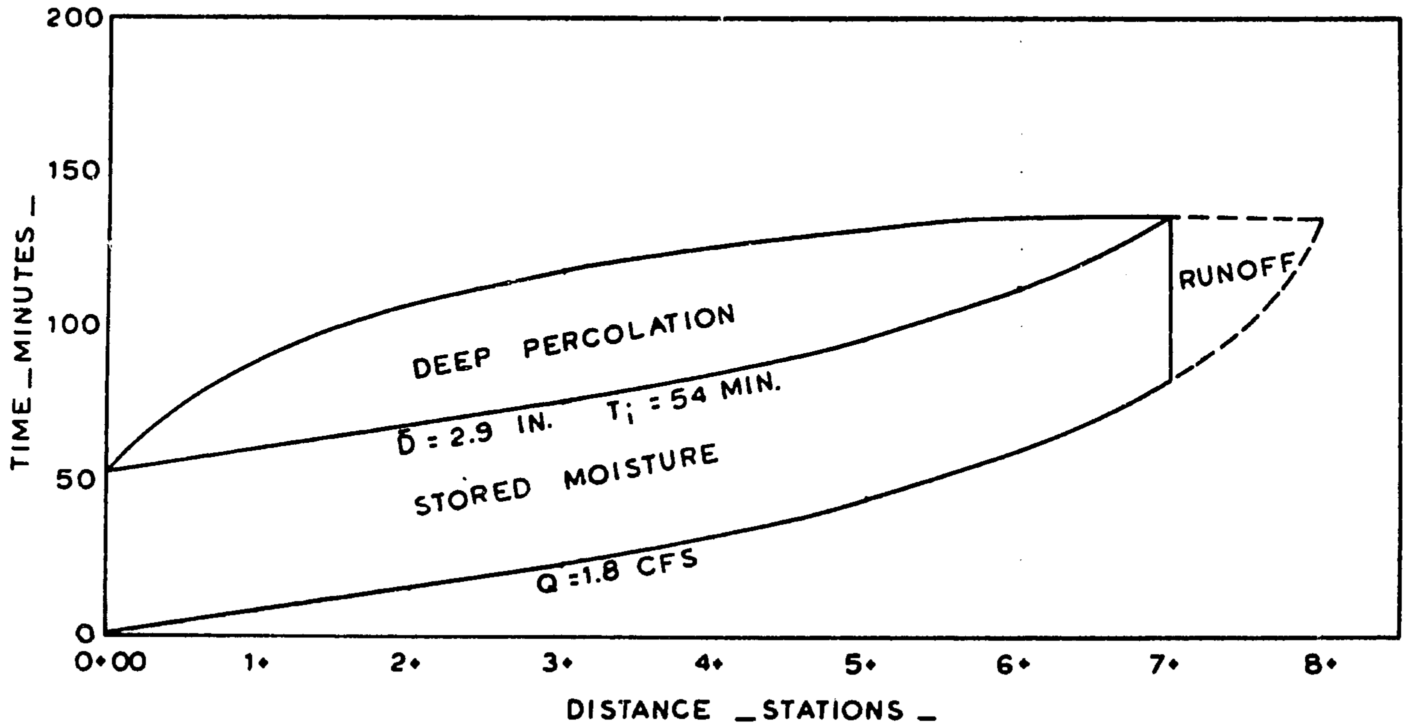


Figure V-6. Anticipated evaluation curves for increased discharge Q and present MAD.

However, using these anticipated curves, the T_o and depth at each station were used to compute the average depth on the entire extrapolated curve as shown on Figure V-6. It was 29.0/8.0 = 3.6 in. Knowing the wetted strip width, 23 ft., and extrapolated length, 800 ft., the area was found to be 0.42 acres. The estimated stream size was found to be

$$Q = \frac{3.6 \text{ in.} \times .42 \text{ ac.}}{(48/60) \text{ hr.}} = 1.9 \pm \text{cfs.}$$

If, on trying the 1.9 cfs stream, cut-off at 48 minutes proved too soon, the stream could be run longer slightly over-irrigating the upper end, or a larger stream could be tried, or MAD increased. It must be remembered that the numbers as developed cannot be considered as precise, but they are very indicative of what can be done.

On the 23 ft. width the desired flow would be about 0.08 cfs per foot. For the available stream of 1.2 cfs, the strips should be about 15 ft. wide which might be impractical to farm. However, it could have a Potential irrigation system Efficiency of about (2.9/4.1) x 100 = 71%. An engineering cost comparison involving a reservoir, larger delivery capacity capable of irrigating several strips or wider ones, and water and labor saving, would probably show such changes to be conomical.

To obtain high efficiencies, it is essential that flexibility in frequency, rate, and duration of water delivery be possible to match field conditions which are constantly varying as crops, MAD, intake rate, retardance, and weather change.

Soil moisture deficiency, smd, at which irrigation should be done varies with root zone depth of annual crops and is fairly constant for perrenial ones. It can be varied within some limits to suit the convenience of labor, crop growth, and irrigation efficiency. For the field evaluated, the deficiency was about 2.9 in. to match a cutting condition of the crop. For a six-foot root zone on this sandy loam soil having about 1.5 in. of available moisture per foot, the percent MAD was (2.9 in./6.0 x 1.5 in.) x 100 = 32%, a very low value. For this soil, crop, and cool climate a MAD of 60% would be reasonable, therefore a soil moisture deficiency of about 60% (6 ft. x 1.5 in.) = 5.4 in. could be used if practical for labor and harvest conditions.

This condition is shown of Figure V-7 for 5.4 in., T_i = 140 minutes, and Q = 1.2 cfs (existing stream size.) The field-obtained advance and recession curves were use unmodified. With the illustrated large increase in soil moisture deficiency, the initial intake rate of the soil would actually be faster and the advance rate would be slower (steeper), and time of lag would be greater. Compensating for this, the actual recession curve would also be slower (steeper) because a decrease in final intake rate due to the longer application rate would prolong run-off. The original curves gave reasonable, though not correct, values to study possible modifications of this extreme magnitude.

The anticipated curves on Figure V-7 show adequate depth infiltered at the beginning, too much on the upper two-thirds, and under-irrigation for the lower end. Runoff was excessive as cut-off occurred 25 minutes after flow reached the end. However, since this strip is the upper half of a 1400-foot field, a very high efficiency using continuous border-strips could be obtained by opening the valve at 7+00 when flow reached this point and closing the valve at 0+00. Runoff would then be entirely utilized, and water would be backed up at the middle compensating for the under-irrigation previously existing. The problem of run-off would occur then at the lower end of the second strip. A dike at that location, ponding water and making possible an earlier cut-off, would bring these two strips to a rather high application efficiency at the increased MAD level, and reduce labor because of lesser frequency.

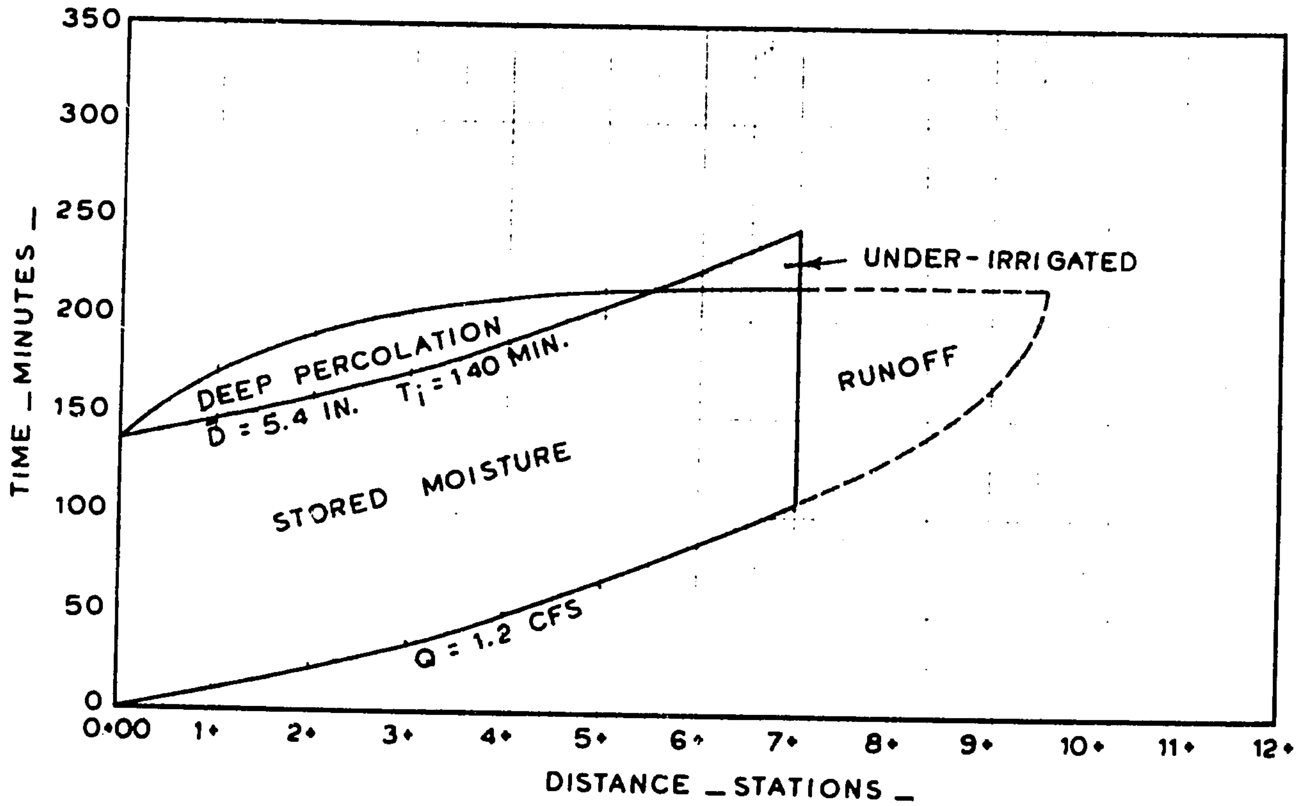


Figure V-7. Anticipated evaluation curves for increased MAD and original stream size.

For the single upper strip, high efficiency is impossible for these conditions as the strip is too short for the large MAD. Other possibilities would be: run two strips with half-size streams which would reduce runoff but over-irrigate the upper end. A return flow system to put the runoff water into storage for later re-use could be used under some conditions.

Strip length can be varied when a supplemental line is installed, or portable pipe is used. As shown, changing MAD requires different length strips which is a very important consideration. With annual crops the expanding root zone requires larger irrigation and longer strips. At the beginning of the season, a strip might be started in three sections, and later cut into two or even one, or sprinklers could be used for the early applications.

For the evaluated strip, if MAD were 5.4 in. and the desired stream flow of about 2.4 cfs were available, the anticipated curves and efficiencies on Figure V-8 would be indicative of the results. The recession curve would be stretched in the middle and be raised because of the lower intake rate caused the longer MAD, and the larger stream would result in a more rapid advance. A PE (SCS) of about 80% would result. This "on paper" study based on the extension of the evaluation data indicates what may be tried in the field. A dike to pond water at the lower end would be a further improvement. It would have been much better to have run several stream sizes at the time of making the evaluations so that a better estimate of different trial advances could be made.

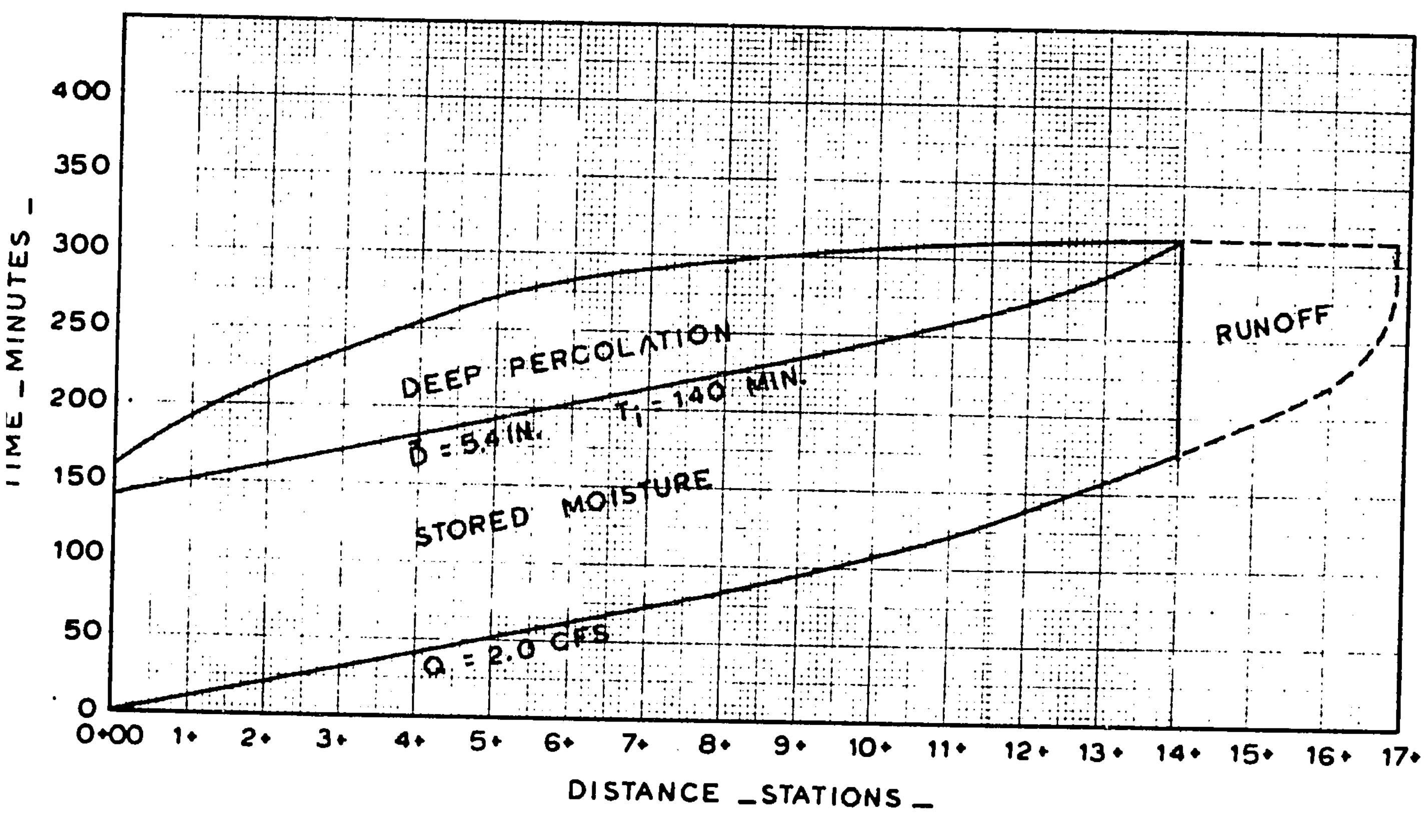


Figure V-8. Anticipated evaluation curves for increased MAD, stream size, and length.

Summary

The additional analysis shows that: much can be learned about the grade of the strip and variations in intake rate by observing the simultaneous changes in shape in the advance and recession curves (see Appendix F); the recession curve shape remains similar for any particular strip condition, and also minor condition changes can have an anticipated effect on the curves; there is only one stream size and resulting advance curve which ideally matches the fixed recession curve; changes in MAD will require a change in length if the correct stream is not changed; and that interrelated adjustment in stream size, MAD, and sometimes length are practical to improve efficiency and save labor. It is essential in order to make the desired adjustments that water deliveries be flexible in frequency, rate, and duration.

CHAPTER VI

BASIN IRRIGATION

Basin irrigation is an easy way to irrigate and adaptable for crops that can stand being partially submerged and for pre-irrigation or leaching. Basins are not recommended for germiniation or where a soil crusting may cause difficultires. Basins may be as small as a few square feet around a young tree or as large as ten or more acres. Such large basins require level, uniform soil within the basin and a large enough stream of water to cover it quickly. The shape ans size of each basin should be selected to match soil and field boundaries. Dikes to create the basins can be farmed over and easily built up and broken down for cultural practices.

Evaluation

The evaluation of basin irrigation is mostly done by observation. The uniformity, inflow rate, flow duration and basin area are required to estimate the Actual application storage Efficiency, AE. Determining exact efficiency values is impractical due to small variations in intake rate in various parts of the basin and/or low spots where water ponds will produce appreciable differences in the depth infiltered. Aerial photos, soil surveys, reaction to tillage, variations of crop production and salinity, etc., may all provide information for selecting basins with relatively uniform infiltration.

The improtant items to be obtained, measured, or observed, are as follows:

1. A sketch, drawn to scale, of the field layout.
2. The soil moisture deficiency, smd and Management Allowed Deficiency, MAD.
3. The rate and duration of inflow into the basin.
4. The way the water spreads, noting the rate of filling and smoothness of the basin.
5. The reate of infiltration, or time required to replace the smd.
6. Any variations in intake rate within the basin.
7. The adequacy or depth of penetration by a probe or an auger.

Equipment needed

1. Soil auger.
2. Soil probe.
3. Watch.

4. Flow measuring device.
5. Surveying tape and compass for measuring the basin areas.
6. Hand level.
7. Staff guage.
8. Forms for recording data.

Field procedure

1. Prepare a map of the basin under study.

2. Make soil moisture deficiency checks in several locations. Observe and note any difference in crop growth, soil texture, profile and smd. Compare the minimum smd to MAD to determine whether it is dry enough to irrigate.

3. Determine the rate of inflow and note the starting and shut off times.

4. Observe the advance of the water front. On the map of the basin sketch the position of the water front at six or eight time intervals. An uneven advancing front line will give an indication of high and low areas. A grid of stakes in the field would increase accuracy, but problems can be adequately identified without stakes unless the basin is very large.

As the water level drops, sketch the position of the receding water front at several time intervals noting any major islands or ponds. The receding water front at succeeding times can be shown on the advance sketch map with a different color and/or type of lines. (The advance and recession maps can be made as overlays using sheets of tracing paper over the base map.) Only moderate accuracy is needed to indicate high or low areas at any point. The difference between the arrival time and the recession time is the opportunity time, T_o.

5. The rate of infiltration cannot be easily determined for the basin (though cylinder infiltrometers can be used for more detailed study). However, a concept of magnitude can be obtained at the same time the smoothness of the field is being observed. A staff gauge or datum stake can be set in the field near the inlet gate or where it can be easily read. A record of gauge readings at various time intervals should be kept.

The time when the water is turned on and off and when the basin is covered should be recorded. Depths and times should be noted after the basin is filled and as the water level drops. This data should be plotted as a cumulative depth/time curve which will be adjusted to pass through the value of the computed inflow depth at the time water disappears from most of the basin surface. The adjusting process is similar to that used for border-strips and cylinder infiltrometers (see p.).

A precise cumulative intake curve cannot be bound, because of filling time, different length of time on various parts of the basin, wind effects which cause the water to stack up against a downwind border, the lateral flow from slow intake areas to those with higher rates, etc. For most operations it is adequate to approximate the time it takes the water to disappear from the basin, since this data is not needed for efficiency computations. If reasonably precise intake data is desired, the procedure described below in 6c will give the best results.

6. Variations in intake rate in different areas of the field can be observed by several procedures which are described below. None of these can be considered as more than an indicator of a problem, but a knowledge of variations is important for estimating uniformity.

a. A slow flow of water toward an area of high intake may be observed if the area is extensive enough to create a noticeable flow. Walking around within the basin after it is filled and stirring up a little suspended soil will make the flow visible.

b. After the basin is filled, small dikes barely reaching to the water surface can quickly be constructed dividing the basin into as many smaller sub-basins as practical. Observation of the drop in water surface, usually measured from datum stakes, will indicate the relative intake rates of adjacent sub-basins. Allowance must be made for the probable differences of relative intake rates because of water not arriving at each sub-basin at the same instant. The absolute intake rates of the sub-basins would not necessarily be meaningfull, since they may be the average of areas with high and low rates.

c. Construct the sub-basins as mentioned above but leave gaps in the dikes. Water will tend to flow through the gaps from sub-basins with low intake rates toward those with high intake rates. This is the most sensitive method to observe dissimilar intake rates. Again allowance must be made if the time the water arrives at each area is not the same.

d. Construct a number of sub-basins prior to the test and quickly turn a measured depth of inflow into each of them. This is done by measuring the flow rate, duration and area covered. Then measure the rate the water level drops. Assuming the depth of water applied disappears from all the surface at the same moment, i.e., level basin and uniform intake, a cumulative adjusted intake curve can be plotted backwards beginning with the point representing the total depth infiltered. The data for the backwards plotting of depths at other times can be obtained from measurement taken from a datum stake, starting immediately after the inflow is shut off and the basin is full. Since the small sub-basins can be filled quite rapidly, the starting time for backward plotted curves can be assumed equal to the length of time between when 0.5 to 0.6 of the sub-basin is covered and the applied water disappears.

e. Cylinder infiltrometers may be used to estimate infiltration characteristics within the basin. However, numerous tests must be made to obtain a reasonable degree of accuracy. Such tests require appreciable labor and sophisticated analytical procedures. But this is the only method capable of giving predictive values.

7. The use of a probe, after the water has just disappeard from the surface, will indicate the depth and uniformity of penetration at that time. Water will continue to move deeper as the upper part of the soil profile drains down to the field capacity. A check at that time or soon afterwards will indicate if water has already penetrated too deep, or is still penetrating. Soil probes do not work will in fine textured soils nor to depths greater than about 3.5 ft. A check with a soil auger a few days later will give more precise information about the adequacy of irrigation, but does not indicate over-irrigation.

Analysis

The objective of an evaluation is to determine the effectiveness of the present management practices and to indicate where improvements can be made.

The soil moisture deficiency, smd, checks compared with the Management Allowable Deficiency, MAD, will tell whether the time of the irrigation is too soon, too late, or at the correct time. It will provide the depth of water to be replaced by the irrigation. It is a key number in computing any efficiency term since it corresponds to the maximum depth of water that can be stored in the root zone at that location.

The depth of water applied is computed by multiplying the inflow rate by the duration and dividing by the area of the basin

$$\text{Depth Applied} = \frac{\text{cfs} \times \text{hrs}}{\text{acres}} = \text{inches}$$

or

$$\text{Depth Applied} = \frac{96.3 \times \text{gpm} \times \text{hrs}}{\text{Square ft.}} = \text{inches}$$

The uniformity of infiltration is important and it can be estimated fairly well. It is affected by duration of water on the surface (Time of opportunity, T_o) and intake rate.

If the basin can be covered in about 1/4 of the time needed to fully irrigate all parts of the basin (Advance Ratio, R = ¼), the adverse effect of the initial wetting on uniformity will be minimum. If the basin were level and the surface became free of water at about the same moment, uniformity would then be very high with an average of about 5% going too deep, since less than 10% more water would be infiltered at the location where water entered the basin than at the far side. This would be true only within the limitation that the intake rate is uniform throughout the basin. The uniformity of intake rate within the basin should be checked by one of the steps listed under point 6 in the Field procedure.

Nearly all of the water ponded in low areas may be considered as going too deep. This is based on the assumptions that the minimum depth infiltered, which should just satisfy the smd, occurs at the first areas exposed in the basin as the water recedes, and that the intake rate is uniform over the basin. This volume of water which goes too deep can be estimated from the average depth of each pond and its area. This volume will be in addition to the approximate 5% going too deep because of the advance time.

To illustrate this, assume that the water disappeared in half of the basin at about the same moment and the remaining portion was ponded with an average depth of 0.4 inches. This would correspond to an average depth of 0.2 inches on the entire area. If 4.0 inches were applied, the loss to deep percolation from the ponded area would be 5%.

The Distribution Uniformity, DU, can be approximated from the observed information as follows

$$DU = \frac{\text{minimum depth infiltered}}{\text{average depth infiltered}} \times 100$$

For basins with no runoff and using the average of the lower 1/4 as the minimum this may be rewritten as

$$DU = \frac{\text{average depth applied - average depth ponded with 1/4 area exposed}}{\text{average depth applied}} \times 10$$

(DU can be more precisely determined by using an involved and detailed procedure similar to that described in Border-Strip irrigation under Adjusted Cumulative Intake. This is done by using the advance and recession maps developed in step 4 of the Field procedure and finding the time and a corresponding Typical depth at about 8 to 12 points representing equal areas and then finding "minimum" and average depths).

Potential and Actual Efficiencies can be estimated when the depth infiltered on the first 1/8 of the area equals the smd. At this point PE and AE are equal to DU, since there is no runoff. When over-irrigation occurs and more water is infiltered into the first exposed area than the smd, the AE will be less than PE.

A little thought will show that basin irrigation can be highly efficient only when the basin is very level, has soils with uniform intake rates and the correct depth is applied rather quickly. Practical problems of non-level fields, even by small amounts, and non-uniform intake rates reduce the PE values appreciably. If smd is not determined and the proper flow rate and duration computed, AE values may be considerably lower. Among all the items concerned with DU and PE, only the volume applied can be accurately obtained. A reasonable value of efficiency can be computed by estimating the water which goes too deep. Problems of slow filling, non-level field and dissimilar intake are identifible and correctable if warrented.

Appendix A
Soil Moisture and Appearance Relationship Chart

This chart indicates approximate relationships between field capacity and wilting point. For more accurate information the soil must be checked by drying samples.

Moisture Deficiency in./ft.	SOIL TEXTURE CLASSIFICATION: Coarse (loamy sand)	Sandy (sandy loam)	Medium (loam)	Fine (clay loam)	Moisture Deficiency in./ft.
.0	(field capacity) Leaves wet outline on hand when squeezed.	(field capacity) Appears very dark, leaves wet outline on hand, makes a short ribbon.	(field capacity Appears very dark, leaves a wet outline on hand, will ribbon out about one inch.	(field capacity) Appears very dark, leaves slight moisture on hand when squeezed, will ribbon out about two inches.	.0
.2	Appears moist, makes a weak ball.				.2
.4	Appears slightly moist sticks together slightly.	Quite dark color, makes a hard ball.	Dark color, forms a plastic ball, slicks when rubbed.	Dark color, will slick and ribbons easily	.4
.6		Fairly dark color, makes a good ball.	Quite dark, forms a hard ball.	Quite dark, will make thick ribbon, may slick when rubbed.	.6
.8	Dry, loose, flows thru fingers. (wilting point)	Slightly dark color. makes a weak ball.	Fairly dark, forms a good ball.		.8
1.0		Lightly colored by moisture, will not ball.		Fairly dark, makes a good ball.	1.0
1.2		Very slight color due to moisture. (wilting point)	Slightly dark, forms weak ball.	Will ball, small clods will flatten out rather than crumble.	1.2
1.4			Lightly colored, small clods crumble fairly easily.	Slightly dark, clods crumble.	1.4
1.6			Slight color due to moisture, small clods are hard. (wilting point)		1.6
1.8				Some darkness due to unavailable moisture, clods are hard, cracked. (wilting point)	1.8
2.0					2.0

Field Method of Approximating Soil Moisture for Irrigation, From Am. Soc. Agri. Engr. Vol. 3, No 1, 1960, by John L. Merriam., California State Polytechnic College.

Appendix B

Stabilizing onflow stream rates from a fluctuating source. For quick approximate checks of irrigation efficiencies, some fluctuation in flow rates is not detrimental. For more detailed studies, stable onflow rates are nearly essential.

The principle of stabilizing flow is to use turnouts of an orifice type such as a gate, siphon, short tube, orifice, etc., in which flow is proportioned to $H^{0.5}$ in conjunction with a bypass controlled by a weir in which flow is proportional to $H^{1.5}$. A 10% increase in H will increase flow in the orifice 5%, but over the weir the flow will increase 15%. The longer the weir and the greater the proportion of flow going over it, the smaller will be the fluctuations on the turnout.

A sample layout is shown on Figure A-1.

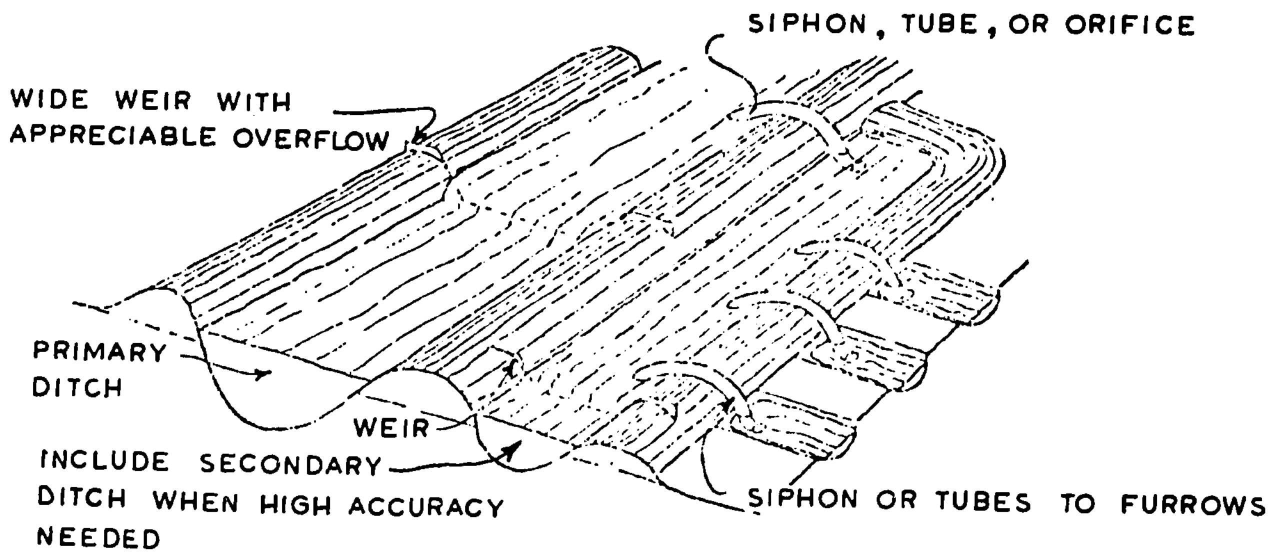


Figure A-1. Flow stabilizing set-up.

Appendix C

Flow Measuring Devices

Flow measurements are an essential part for successful and good irrigation and of all evaluations. The degree of accuracy needed varies with conditions. Many commercial measuring instruments are available and many improvements can be made based upon hydraulic principles. The ones commonly used for evaluation and their operation are described, and others are mentioned. Accuracy of all but the volumetric procedure will seldom be closer than 5%. More detailed discussions and tables may be found in texts and pamphlets. Figure A-2 contains graphs of flow rates of siphons and Parshall flumes and powers of numbers.

Volumetric. From sprinklers flow is diverted by a short section of hose into a container of known volume, usually one gallon. The time to fill is measured. The container must be large enough so that duration of flow can be accurately measured. A stop watch improves precision.

In furrows, the container can be set into a hole and flow directed into it by a short tube. At the upper end of furrows using gated pipe or siphons the process is similar.

With an adequate size container, this is the most accurate procedure.

Orifice. The principle of measuring head on an orifice or short tubes and relating this to the corresponding velocity through an area has many adaptations. $Q = AV = C\ A\ 8\ H^{0.5}$. Where C is a shape and entrance condition constant; A is area in square feet; and H is head in feet, Q will be given in cubic feet per second, cfs. Values of C are published for many conditions. The minimum value for a sharp edged orifice is 0.61 with 0.64 being more nearly an average. Head is measured from the water surface to center of the orifice and should be a minimum of one diameter for accurate flow readings. For submerged orifices, H is the difference in water surfaces.

Standard conditions at the entrace to orifices or short tubes require that they be clear of flow distorting conditions for at least one diameter on all sides, and that the flow approaching it be slow and uniform. The edge of the orifice must be "sharp" (unrounded) and the face smooth. Orifice plates may be submerged in holes so that there is adequate space around the orifice on all sides.

Parshall flumes. A special horizontal, converging channel carefully made to specific dimensions is well adapted to evaluation techniques. It requires very little drop through it, and is usually free from sediment collection in it. For setting in furrows to measure inflow minus outflow, they should be set as deep as practical to reduce ponding upstream, but not deep enough to be "drowned out" by downstream flow covering the shooting flow through the throat. Small canvas aprons on the upper end can be buried in the soil to prevent bypass flows. The flumes must be set horizontal using a spirit level. Larger flumes are usable to measure onflow to border strips.

Depth of flow is measured at one-third the throat length from the upstream edge. It must be measured accurately and the depths converted to flow rates by using tables or Figure A-2. The use of a point gauge to measure down to the water surface gives the best accuracy.

Weirs. A weir is a barrier across an open channel and water falls freely over it. There are weirs of many shapes. The common ones are 90° \/, rectangular |_|, and trapezoidal _/, with 1:4 side slopes. The V notch is adapted to accurate measurements of low flows and may be used in furrows on moderate to steep grades. The other two are useful in larger channels. All weirs require appreciable loss in head.

For standard conditions, the sides and bottom of the weir notch should be two to three times the depth of flow over the weir away from the adjacent channel. The edges of the weir must be "sharp" (unrounded), the face smooth and vertical, the flow approaching it must be slow and uniform, and water must not back up above the lip on the downstream side.

Head, H, on weirs is measured by the height of the water above the weir crest at a location at least three times the depth of overflow away from the crest. Flow in cubic feet per second, cfs, is given for V weirs by $Q = 2.5H^{2.5}$; for trapezoidal by $Q = 3.37\ L\ H^{1.5}$; and for rectangular by $Q = 3.33(L - 0.2H)H^{1.5}$, where L is the crest length in feet. For more precise weir calibration, publsihed values of C must be consulted. Flow depth should be greater than 1/2 in. (See Figure A-2 for powers of numbers.)

Pipe jets - horizontal and vertical. A stream of water flowing full from the end of a horizontal pipe in a simple flow measuring device. By measuring the horizontal distance, L (inches) from the end of the pipe to where the jet has dropped 12 in., the flow in gallons per minute, gpm, can be computed. $Q = AL$, where A is the area of the pipe in square inches. For other flow conditions of sloping pipe or partially full, tables may be consulted.

Flor low vertical jets where height of jet, H ,is less than 0.4 diameter, d , weir flow gives practical answers. $A = 8.8d^{2.5}H^{3.5}$ with Q in cfs, d and H in feet.

For vertical jets with H greater than 1.4 d, $Q = 5.6d^2H^{0.5}$. For values of H between 0.4 and 1.4 d, the values by either equation are a little higher than actual flows.

Direct velocity measurement methods are numerous. Current meters are used to measure the velocity at several points. Eight-tenths of the velocity of a surface float approximates the average velocity along the path of the float. The float is affected by wind unless submerged. A vertically held stick maintained close to the bottom of the channel and moved by the current will indicate the average velocity. It must be tried along several paths. For all of these methods the representative area of each path multiplied by the velocity must be totaled for the entire cross section of the channel to obtain the total flow.

Dyes such as fluorcein, which is visible at a few ppm, can indicate velocity.

Indirect velocity measurement methods consist of converting velocity energy to elevation pressure in feet which can be used to compute velocity in feet per second , fps , $V = 8\ H^{0.5}$. By inserting an I-shaped tube pointing directly into the stream, water will rise in the vertical section a height , H , above the water surface (Pitot gauges.) Also a hose or tube may be used. Refinements of this procedure are available commercially, especially for pipe flows and sprinkler jets. A flat board of width about equal to the water rise can also be used. When the board is placed across the stream, water is forced up the front face H distance. This method is reasonable only for velocities from about 1.5 to 5.0 fps with H values from 0.04 ft. to about 0.4 ft.

Constricted channels, artificial or natural, can be used in conjunction with hydraulic principles to measure flows either by forcing critical depth or non-uniform flow.

Commercial meters of various types are available in many sizes.

<u>Summary</u>. The commonly used portable devices used for evaluation are for sprinklers - calibrated container and watch, Pitot pressure gauge and orifice area; for furrows - small Parshall flumes, orifice plates, calibrated containers, short tubes, and V notch wier, for border strips. Parshall flumes, weirs, horizontal or vertical jets, and commercial meters.

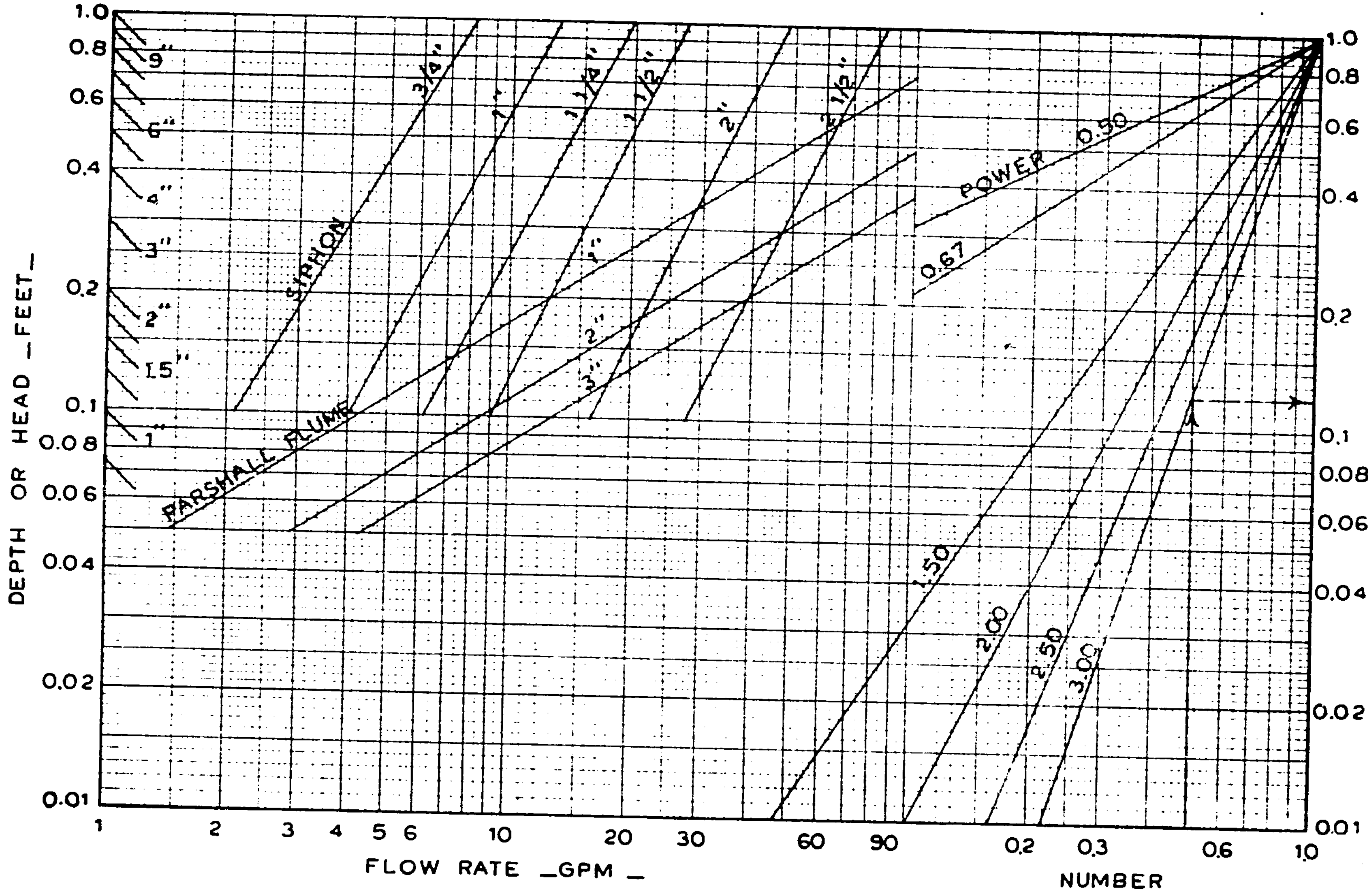


Figure A-2. Flow rates of Parshall flumes and siphons and powers of numbers.

Appendix D

Procedure to Draw Furrow Intake Curves for any Spacing from Field Test Data.

1. On a sheet of 3 x 3 cycle logarithmic paper, place title showing location, date, soil, slope, moisture condition, and furrow shape and condition. Mark bottom scale *time* from 1 to 1000 minutes; and vertical scale for two sets of *intake* units gpm/100 ft. and depth, inches from 0.1 to 100 or 0.01 to 10 as needed.

2. From furrow tests data, plot intake rate gpm/100 ft. versus time, and draw a straight line through the points for each test. A line typical of all tests is then drawn completely across the paper. If the original lines vary greatly, two typical curves may be drawn to represent the range.

3. Measure the horizontal, h, and vertical, v, length of the line using any convenient linear scale since only the ratio is needed.

4. For the desired furrow spacing, S, in feet, compute a time ,T, in minutes using the equation $T = 60(1 - \frac{v}{h})S$, and mark it on the gpm/100 ft. intake curve drawn in Step 2.

5. Measure the distance from this point to the line T = 1.0 minute (the left border.) Measuring can be done with any linear scale or by making marks on a piece of paper.

6. Measure down the distance found in Step 5, from where the gpm/100 ft. intake curve crosses the line T = 1.0 minute, and mark it.

7. Through the two points found in Steps 4 and 6, draw a line that represents the accumulated intake after any time, T, for the desired furrow spacing, S.

8. For other furrow spacings, repeat Step 4 and draw lines through the corresponding T points parallel to the line in Step 7.

The resulting cumulative curves are representative of the test, but may not be construed as being more than a reasonable guide for other conditions since intake rate varies with antecendent soil moisture content, stream size, whether the furrow is new or reused, soil structure, etc. Intake rate in in./hr. for specific furrow spacings may be drawn as shown Figure IV-2, page IV-13.

Appendix E

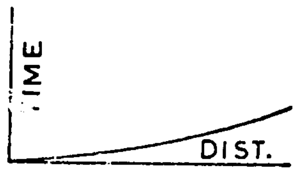
Cylinder Infiltrometers. The cylinders should be 10 in. or more in diameter, 12 in. to 15 in. long, and be of 14 or 12 gauge steel. They should be driven straight without wobbling to have no open cracks around the edge, to a depth of about 6 in. A heavy steel plate to cover the upper end, for protection of the edges, and a heavy hammer are used. Some protective material such as vegetation, a piece of paper or cloth, is placed in the bottom of the cylinder to protect the soil from erosion when water is poured in. If the protective material has any appreciable volume, it must be removed immediately after filling of the cylinder and before the first reading. A reference datum is chosen and marked on the rim of each cylinder. At some full minute, 4 in. to 5 in. of water is quickly poured in one cylinder. As soon as possible the first measurement is made from the datum down to the water surface. On most soils the second reading is taken at one minute, but on soils that have cracks or very high intake rates, the second reading should be taken at 30 seconds followed by a third at one minute. Subsequent readings are taken at increasingly longer intervals to obtain eight or more measurements during the test. If the cylinder needs re-filling, before and after depth readings are quickly taken, but recorded as though at the same time. The other cylinders are filled in sequence, as convenient.

Water surface readings are made only to the nearest 0.05 in. since the plotting procedure averages out the values, and the variation between cylinders is appreciable. They are made from the datum to the water surface using a rule, a point gauge, or a hook gauge, though the latter does not permit the last inch or so of depth to be measured.

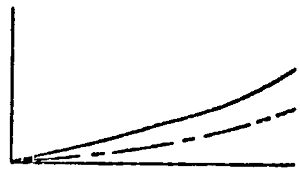
Appendix F

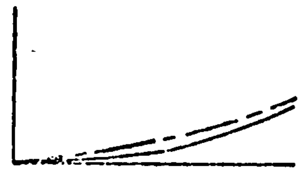
Advance and Recession Curves for Border-Strip

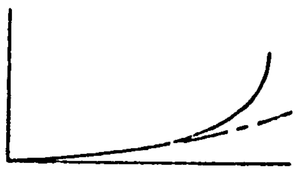
NORMAL CURVE — Advance Curves

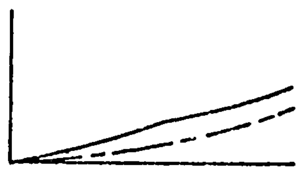


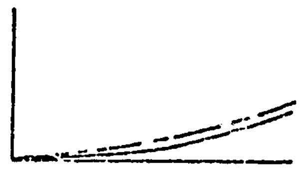
A gradually steepening sickle-shaped curve.

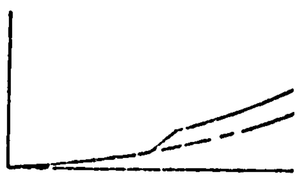

Faster intake in upper half of strip.


Slower intake in upper half of strip.


Cutoff too soon.


Flatter slope in upper half of strip.

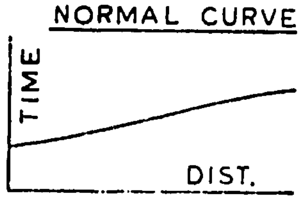

Steeper slope in upper half of strip.


Low pocket in central portion.

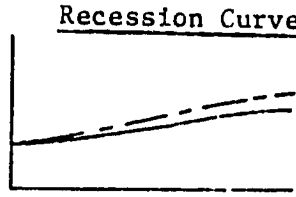

Faster intake or flatter slope in central portion.

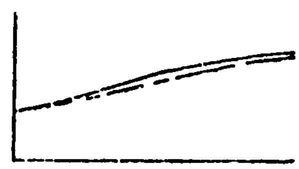

Slower intake or steeper slope in central portion.

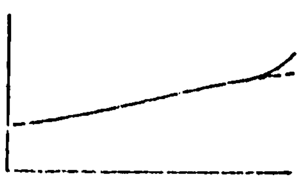
NORMAL CURVE — Recession Curves

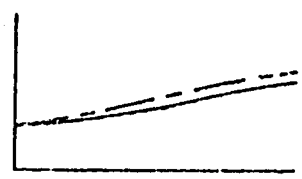


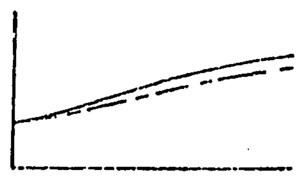
A slightly S-shaped curve.

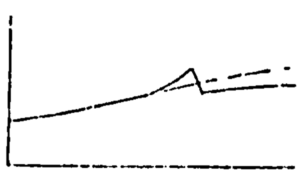

Faster intake in upper half of strip.

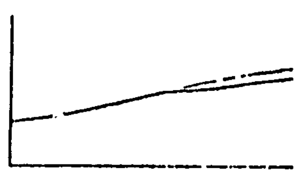

Slower intake in upper half of strip.


Dike at lower end ponding water.


Steeper slope in upper half of strip.


Flatter slope in upper half of strip.


Low pocket in central portion.

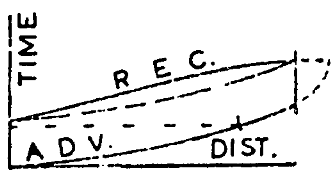

Faster intake or steeper slope in central portion.


Slower intake or flatter slope in central portion.

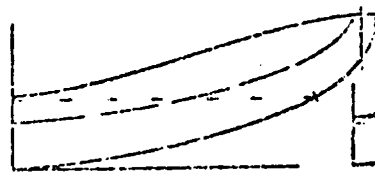
Appendix F (continued)

Combined Curves

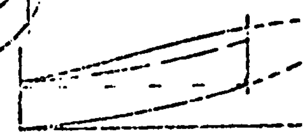
NORMAL CURVES



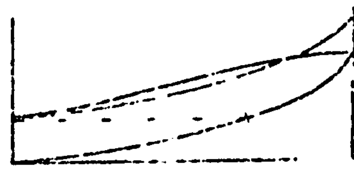
Advance and Recession nearly parallel. The Irrigation is always parallel to Advance. Time of Cutoff equals Time of Irrigation minus a small lag time. Location of cutoff about 3/4 of length but such that lower end adequately irrigated with very little runoff.



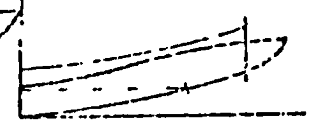
Strip too long, over-irrigates whole strip.



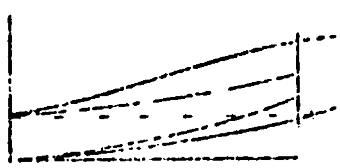
Strip too short, large amount of runoff, over-irrigates lower portion.



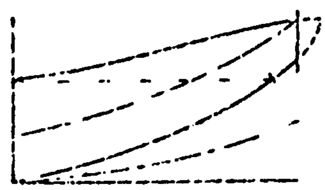
Strip too long, under-irrigates the lower portion, no runoff.



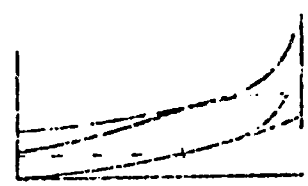
Strip too short, under-irrigates whole strip.



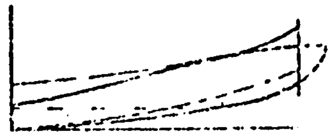
Stream too large, over-irrigates lower portion,



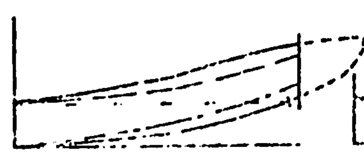
Stream too small, over-irrigates upper portion.



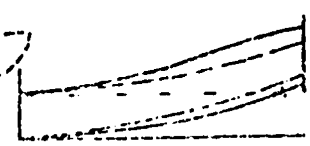
Cutoff too soon, under-irrigates whole strip.



Stream too large, under-irrigates upper and lower portions.



Steeper slope in upper portion, adequate irrigation, excessive runoff.



Slower intake in upper portion, adequate irrigation, excessive runoff.

Appendix G

Soil Probe

The soil probe, which is used to determine in the field the depth of penetration of irrigation water, is a very useful tool in irrigation practices. Essentially the probe consists of a pointed 3/8 in. steel rod 5 ft. long, with a handle at one end which gives the probe a T shape appearance. To facilitate the measurements, the rod can be marked in foot increments or in any other suitable units.

The irrigator can determine the depth of penetration by simply pushing the soil probe into the wetted soil. The probe will easily penetrate the wetted profile and will encounter more resistance to penetration when the deeper portion of the soil profile is reached. The irrigator would then measure the penetrated depth by means of the marks on the rod. By systematically repeating this procedure, the irrigator will have a very good idea of water penetration in the irrigated field and be able to exercise good control of irrigations. Lateral water movement can also be determined by the probe, such as in furrow irrigation, where it may be advantageous to measure the lateral spread of the irrigation water from the furrows.

GLOSSARY

Curve Types

Advance curve

A plot representing the distances traveled by the water front and the elapsed times of irrigation for those distances. It is usually plotted on rectangular coordinate paper with the distance along the horizontal or "x" axis. The curve will rise smoothly upward. To facilitate extrapolation of the advance curve beyond the true field length, it may be plotted on logarithmic (log-log) graph paper. For convenience it may be plotted on the same paper with the depth of infiltration versus time or cumulative intake curve.

Irrigation curve

A line plotted at a uniform time interval above the advance curve. The interval is the time, T_i, needed to infilter the depth corresponding to the soil moisture deficiency, smd. The irrigation curve has an identical shape to the advance curve and shows how long water should be on the soil surface. Ideally the recession curve would match the irrigation curve, but this is not possible.

Recession curve

A plot of the time versus distance from the beginning of irrigation when the water has disappeared from the surface along a series of points down an irrigated strip. The time is measured from the beginning of irrigation. For border strips it is usually an upward sloping curve, which may have many variations depending on soil and slope uniformity. It may dip down at the far end if the stream is cut off too soon, the soil has a high intake rate, or the gradient is too flat. If there is ponding at the end or at the low spots, the curve may swing up at the end. For furrows,recession curves may be approximated by horizontal straight lines occuring shortly after the stream is turned off, i.e., the water disappears from the whole furrow almost simultaneously.

Efficiency Terms

Actual application storage Efficiency, AE

The minimum infiltered depth of irrigation water stored in the root zone expressed as a percentage of the average depth of water applied. It can refer to one irrigation or a season, and to a farm, field or a unit. Conveyance and supply losses are not included.

For all methods

$$AE = \frac{\text{minimum depth infiltered and stored in root zone}}{\text{average depth applied}} \times 100$$

for sprinklers

$$AE = \frac{\text{minimum depth infiltered and stored in root zone}}{\text{average rate applied x application time}} \times 100$$

With a full or excessive sprinkler irrigation, the application time, T_a, is equal to or greater than the minimum time for a full irrigation, T_i, therefore, when storage ration, SR, is 1.0

$$AE = \frac{\text{minimum rate caught x T}}{\text{average rate applied x } T_a} \times 100$$

The AE tells how effectively water is being applied. It is most significant when an irrigation that satisfies the smd has been applied, SR = 1.0. Very low values of AE indicate over-irrigation or careless operation, with some areas receiving little water. Whenever the Potential irrigation system Efficiency, PE, is greater than AE, management practices can be improved. Moderately low values of AE may be economical, they also may be associated with Intentional Under-Irrigation (see the Introduction Section).

Application storage Efficiency, E_a

The average depth (instead of minimum depth) stored in the root zone expressed as a percentage of the average depth applied.

$$E_a = \frac{\text{average depth stored in the root zone}}{\text{average depth applied}} \times 100$$

The E_a equals the AE when a full irrigation satisfying the smd over the entire field is applied, i.e., SR = 1.0. However, the E_a gives no indication of the level of SR and even with exaggerated under-irrigation (like throwing a cup of water on a field) E_a may equal 100%. The E_a merely shows that the water was stored within the root zone. Therefore, E_a must be considered in conjunction with DU and SR. Where intentional under-irrigation is used and SR is less than 100%, AE cannot be used and E_a should be utilized.

The term "application efficiency" has often been given broader meaning elsewhere to include the concepts of beneficial use. In this broader concept the following water classifications have been included in the numerator making up E_a: water needed for leaching to maintain a favorable salt balance, water evaporated from plant leaves, which reduces transpiration by similar amounts, and water saved from deep percolation being used as it passes in transit through the soil profile. These waters cannot be measured as a deficiency or replacement in the soil moisture reservoir. Therefore, they must be considered in some other way and are excluded from the definition of E_a or AE. There can be no comparison between irrigation methods or evaluations unless these waters are considered as separate items.

The leaching requirement varies with crops, water quality and desired level of production. Therefore, it must be considered as a separate amount for each specific condition not related to the soil.

Evaporation from wet leaves during sprinkling offsets a like amount of transpiration that would have been satisfied from soil moisture storage. This can be used to increase the interval between irrigations by about the portion of the daytime during which water was being applied since negligible soil moisture is extracted while irrigating.

For all irrigation methods a reduction in potential deep percolation loss occurs as a crop utilizes moisture while it is still draining trhough the soil profile. With deep rooted crops on finer textured soils this transient water may amount to several days of the transpiration requirement. Most logically this transient water could be allowed for computations by increasing the value of the available moisture in the soil and the MAD. However, for practical purposes it is usually ignored, since it is difficult to measure or estimate. (It could have an appreciable effect on the efficiency terms, especially TR, and on anticipated frequency if computed evapotranspiration rates were precise, but does not occur in under-irrigated areas.)

Infiltration storage Efficiency, E_{is}

The average depth (or volume) stored in the area wetted and expressed as a percent of the average depth (or volume) infiltered into the wetted area.

$$E_{is} = \frac{\text{average depth infiltered and stored in the wetted area}}{\text{average depth infiltered into the wetted area}} \times 100$$

The E_{is} is useful to distinguish between the irrigation losses that are lost to deep percolation and those either lost by evaporation before reaching the ground or by runoff.

Potential irrigation system Efficiency, PE

The measure of system performance attainable under reasonably good management when applying a full irrigation.

$$PE = \frac{\text{minimum depth infiltered just equaling smd or MAD}}{\text{average depth applied}} \times 100$$

The PE is a particular and identical value of AE when the desired depth of water has been infiltered. A low value of PE is usually associated with poor system design (unless intentional for economic reasons). The difference between PE and AE is a measure of management problems.

Meaningful comparisons between several systems modifications or methods can only be made by comparing values of PE. They must be made when applying similar MAD depths, and with identical specification of "minimum" depth. Economic comparisons must also include costs and crop production factors.

Irrigation Management Concepts

Adequate irrigation

An irrigation in which the Management Allowed Deficiency, MAD, is replaced in all the area or depth planned for irrigation. It is usually associated with an irrigation practice where only part of the potential root zone is watered.

Alternate sets

A practice mainly used for portable sprinkler irrigation to improve Distribution Uniformity, DU. It consists of placing the sprinkler line at each irrigation midway between the sets of the previous irrigation. This usually improves DU when the two complete cycles are superimposed, though each single set may have had a low DU value. Also it frequently allows using a move distance greater than would normally provide an acceptable single-set DU value. This permits a saving of labor, reduces average application rates, and may make it possible to irrigate a larger area in the same period of time. Care must be taken with this procedure, so the extra deficiency that will occur midway between the wide lateral sets does not severely stress the crop before the next irrigation is applied to compensate.

This practice is sometimes called alternate furrows for row crops or alternate middles for orchards or vineyards.

Alternate side irrigation

A practice of wetting one side of a crop and then at about half the normal irrigation frequency applying water to the other side, thus providing full coverage at about the normal frequency. This practice is desirable for several reasons. It permits the crop to function with less severe stress than would be possible if the entire root system reached MAD simultaneously. This may permit the choice of a larger MAD than would normally be selected. Under this program at least one side of the plant always has moisture available at stresses of at least half or less than MAD. It also provides reserve easily available moisture for sudden or high transpiration demands.

Alternate side irrigation improves the efficiency of light irrigations which allows twice as much area to be covered during each cycle. It may require more effort but very little more time for the irrigator.

Full irrigation

An irrigation in which the soil moisture deficiency, smd, is fully replaced in all the area.

Leaching requirement

The depth of infiltered water required to dissolve and transport enough salts through the soil profile to maintain a favorable salt balance for economic plant growth.

Limited irrigation

An irrigation management concept in which the soil moisture deficiency, smd, is not fully replenished in the entire root zone depth and/or area, but the frequency is increased so there will be no decrease in yield.

Management Allowed Deficiency, MAD

The MAD is expressed as the allowed soil moisture deficiency used to schedule irrigations so that net crop returns are maximized. It is first related to a soil moisture and crop stress and is expressed as the percent of the total available soil moisture that can be extracted from the root zone between irrigations to produce the best economic balance between crop returns and irrigation costs. Secondly, it is expressed as the corresponding depth deficient for a given root depth and soil having a specific available moisture content. This deficiency is related to a soil moisture stress, at which an irrigation should be applied.

The evaluation of furrow and border-strip irrigation systems should be made when the MAD is reached, since intake rate, water movement and duration of irrigation are greatly affected by soil moisture conditions. Because of the appreciable effect of the MAD on these factors, small variations in the MAD become one of the important management tools for obtaining desired operation improvements for surface systems, especially border-strips. This is true because of the rapid decrease in infiltration rate as the duration of application continues.

Minimum depth infiltered

This term, as used in the several equations, is defined in three ways:

1. The absolute minimum measured.

2. The average of the lowest 1/4 of the values (proposed by the Soil Conservation Service, USDA).

3. The average of the lowest 1/2 of the values (used in Christiansen's Coefficient of Uniformity).

The first one implies that no area receives less than the measured minimum, the second that 1/8 of the area receives less and the third that 1/4 receives less.

For the concept of efficiency to be practical, the area below "minimum" must be small but also greater than zero. The SCE minimum is recommended for normal use in evaluations.

Return flow system

A system to collect and re-use runoff water by either pumping it back to the supply or sequentially using it on a lower field, often a reservoir is required for a flexible operation.

Stress irrigation

An irrigation management concept in which the depth and/or frequency are not sufficient for maximum production, but are designed to increase economic returns or yields per unit of water.

Tipping sprinkler risers

Tipped sprinklers along the sides and ends of fields will reduce the trajectory distance and cause the water to fall in closer instead of being thrown past the field boundary. The practice of tipping or bending risers to reduce the trajectory to about half the normal throw will approximately compensate for not having a line of sprinklers beyond the last set to apply the usual overlapping applications. It should only be used on mature crops which will not be damaged by the low-angle jets.

Ratios

Advance Ratio, R

It is the ratio of the time it takes a furrow stream to reach the lower end of the field, T_{adv}, to the length of time the water is at the lower end, $T_{o(L)}$.

$$R = T_{adv}/T_{o(L)}$$

For design or where the furrow system is well operated, the water should be at the lower end just long enough to provide the desired irrigation, T_i, or

$$R = T_{adv}/T_i$$

The advance ratio is closely related to the uniformity of infiltration of water along a furrow. Values as small as 1/4 result in a uniform application, with only about 10% more water infiltering at the upper end than at the lower. A faster advance with R equals 1/5 only slightly improves uniformity. Ratios as high as 1/3 or 1/2 may be more economical although not as uniform, since at 1/2 about 50% more water will have infiltered at the upper end than at the lower.

Storage Ratio, SR

This is the water stored in the root zone expressed as a percentage of average water storage capacity (or average soil moisture deficiency, smd).

$$SR = \frac{\text{average depth stored}}{\text{average depth storable (smd)}}$$

The SR tells how well the average smd was satisfied. When SR = 1.0 the irrigation is either full or excessive and if less than 1.0 the field is under irrigated in all or part of the area. Therefore, it must be utilized in conjunction with the Distribution Uniformity, DU, since the SR alone does not indicate much about the quality or management of the system. This term has sometimes been called Storage Efficiency.

Transpiration Ratio, TR

This is the irrigation water transpired by the crop expressed as a percentage of the irrigation water applied.

$$TR = \frac{\text{average depth transpired}}{\text{average depth applied by irrigation}}$$

Under sprinkler irrigation transpiration may be reduced by evaporation directly from the wet leaves during a day time. This direct evaporation may be included as compensating transpiration and not considered as a water loss. However, it cannot be included as soil moisture in the other efficiency terms. Therefore, it must be included as directly meeting part of the transpiration, i.e., reduces the frequency needed to satisfy smd. It will be negligible during night sprinkling but significant during the day.

Water in excess of the smd which might otherwise be lost to deep percolation may be consumed before it percolates out of the root zone. Thus the average depth transpired could exceed the smd and thus increase the TR.

The amount of stored water available for transpiration can be increased by reducing soil surface evaporation losses. Therefore, the TR can be increased by mulching, shading by crops, lowering the frequency of irrigation, or wetting only part of the surface area. (See Intentional under irrigation in the Introduction Chapter).

Soil Moisture Terminology

Available moisture

The moisture (or water) held in the soil between the field capacity and the wilting point.

Field Capacity, FC

The moisture (or water) held in the soil after rapid drainage has ceased. This usually occurs one to three days after the soil has been irrigated. It can be expressed as a percent of the dry weight of the soil, as a percent of the volume of the soil, or as a depth of water per unit depth of soil.

Soil moisture deficiency, smd

Soil moisture deficiency is expressed as a depth of water indicating the dryness of the root zone at a particular time. This depth is numerically identical to the depth of water to be replaced by irrigation under normal management. Therefore, the idea of moisture deficient in the root zone is preferable to the commonly used concept of depth of water in the soil. How dry the soil should be before irrigation is needed is related to the soil moisture tension at that smd and how well crops will grow at that stress. Some crops produce better when kept moist by frequent irrigation, however, diseases and pest problems may also be increased. Other crops may produce more economically when allowed to become quite dry between infrequent irrigations which also reduces irrigation labor costs.

Wilting Point, WP

The moisture (or water) held in the soil at which plants begin to show severe signs of wilting, since they can no longer extract moisture rapidly enough.

Streams

Initial stream

The stream started down the furrow or border-strip. It is usually fairly large, but should be non-erosive. However, it may be smaller than the largest available stream.

Cut-back stream

The stream size to which the initial stream is reduced to minimize runoff. In furrows, the cut-back should be made shortly after the flow has reached the lower end, but it must remain great enough to continue to reach the lower end. For border-strips, the initial stream is reduced or shut off shortly before it has reached the end. On strips that are too short for normal operation, the stream must remain large enough to permit water to spread across the entire strip.

Time

Time of advance, T_{ad}

The duration of time it takes water to advance from the upper to the lower end of a field.

Time of application, T_a

The duration of time water is flowing into the area.

Time of irrigation, T_i

The duration of time water should be on the surface to replace the soil moisture deficiency, smd.

Time of Lag, T_L

The duration of time it takes the water to disappear from the upper end of a field after it has been turned off, $T_L = T_o - T_a$.

Time of opportunity, T_o

The duration of time water is on the soil surface with the opportunity to infilter.

Uniformity Concepts

Coefficient of uniformity, Cu

A common way to present sprinkler uniformity is the Cu, originally presented by Christiansen, which is a statistical representation of the catch pattern. When expressed as a percentage, it is calculated by

$$Cu = (1 - \frac{\Sigma d}{Mn}) \times 100$$

or

$$Cu = \left(1 - \frac{\text{average deviation from the average catch}}{\text{average catch}}\right) \times 100$$

where Σd is the summation of all the absolute deviations; M is the mean value of the catch in ' ' the containers in a combined pattern; and n is the number of the containers.

Distribution Characteristic, DC

For a single non-overlapping sprinkler, the DC is the percent of the total wetted area that has infiltered more than the average depth.

The DC relates to the uniformity of that portion of the central wetted area that may contribute to deep percolation losses even under good management. High DC values indicate that potential deep percolation losses are low and the adequately irrigated area may be relatively large. The DC can approach 100% which indicates an extremely uniform application, providing there is very little overlap or tree interference.

Distribution Uniformity, DU

The Distribution Uniformity gives an indication of the uniformity of infiltration throughout the field.

$$DU = \frac{\text{minimum depth infiltered}}{\text{average depth infiltered}} \times 100$$

The DU is useful as an indicator of the magnitude of the distribution problems. A low DU values indicates there will be excessive deep percolation losses and a potential high water table if adequate irrigation water is applied to all areas. If excessive deep percolation is controlled, the area receiving the minimum depth will be badly under-irrigated.

Emmission Uniformity, EU

EU is the rate of discharge available to the plant receiving the least water expressed as a percentage of the average rate of discharge per plant.

$$EU = \frac{\text{minimum rate of discharge per plant}}{\text{average rate of discharge per plant}} \times 100$$

The EU is an important concept in small single tree basin, trickle, and high density undertree sprinkler irrigation systems. Where one or more trees are served by each emitter (bubbler, trickler, or sprinkler), the minimum and average emitter discharges can be substituted in the EU formula.

However, in trickle irrigation where several emitters may supply a single plan, the minimum and average discharge of the group of emitters used per plant should be considered. (The minimum should be defined as the average of the low 1/4 of the groups.)

Often these systems with closely spaced emitters are only designed to wet part of the potential volume. (Such systems would be classed in the intentional under-irrigation group.) For these systems the E_a has significance when defined in volume terms, and EU is comparable to DU. For trickle and micro basin systems where there is no drift loss, EU = DU if each emitter group wets a similar area (or volume) of soil.

For trickle, basin and other irrigation systems with no runoff, 100 - E_a is essentially the percentage of the applied water lost to deep percolation. Consequently the AE of such systems equals the proportion of the applied water which is stored in the root zone times the uniformity of application. Therefore, for trickle and micro basin irrigation systems

$$AE = \frac{E_a \times EU}{100}$$

and assuming all applied water infiltrates

$$AE = \frac{E_{is} \times EU}{100}$$

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