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Evaluation of Sprinkler Irrigation Systems in Northern Utah

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By Jay M. Bagley and Wayne D. Criddle Bulletin 387

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The Weber Basin Project will supply water at a high level so that power requirements for sprinkler irrigation will be at a minimum

ACKNOWLEDGEMENT

During the winter of 1952-1953, representatives of the Reynold's Metal Company requested the Utah State Agricultural College to investigate the use of aluminum for irrigation purposes. After joint development of a work plan, the company made a cash grant to the college for use in making the study. Graduate students were employed to carry on the field work and help with the analysis. Dr. Dean K. Fuhriman, formerly professor of irrigation and drainage, was project supervisor until July 1954. During the balance of 1954, Professor Cleve H. Milligan directed the work and the authors of this report were given the responsibility of completing the study and preparing the final report. To all of those who have either directed the work or assisted in the field we express our sincere appreciation. We are grateful to George D. Clyde, formerly chief, Division of Irrigation and Water Conservation, Soil Conservation Service, for his assistance in planning and setting up the study. Murray J. Gavel, graduate student, worked in the field during the summer of 1954 and prepared a master's thesis on the results which has been most helpful in the preparation of this report.

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Summary and Conclusions

SPRINKLER irrigation will continue to expand in Utah as well as in other irrigated areas of the world. This method of irrigation is suitable to all farm crops grown in the state and to most soils. It is particularly adapted to steep foothill areas where the water supply can be obtained at higher elevation and pumping is not necessary to develop pressure for the sprinkler systems. Also, much of the irrigated land of the state, particularly along the Wasatch front, is owned and operated by "part-time" farmers. Having the water under complete control and the irrigation schedule worked out to fit their needs can be of great value. However, canal companies must change existing water delivery schedules to make sprinkler irrigation workable. This method of irrigation is most satisfactory with small more nearly continuous flows of water during the peak use period instead of large intermittent deliveries.

Maximum benefit from a sprinkler irrigation system cannot be realized unless it is properly designed and operated. Development of a successfully designed system and its operation require a knowledge and understanding of the complex plant, soil, and water relations. These factors must be considered and the system then designed to meet the farmer's desires and work schedule. It should be the responsibility of the sprinkler system designer not only to install the equipment properly, but to train the farmer in its correct use.

The following conclusions can be drawn from the sprinkler irrigation studies conducted in northern Utah during 1953 and 1954.

1. Suitable sprinkler systems for northern Utah lands will probably cost from $75 to $85 per acre, based on 1954 prices.

2. More than 40 percent of the sprinkler systems studied are inadequately designed to meet peak water use requirements. Of the others, about 15 percent have not been meeting these demands because of improper operation.

3. Farmers generally are not applying sufficient water each irrigation for optimum crop growth or minimum water application cost.

4. The sprinkler system must be capable of delivering a water supply of about 10 gallons per minute per acre flow during the hottest part of the summer for the crops and conditions found in northern Utah. One major reason for this large flow requirement is that field shapes are irregular.

5. Total labor requirements will be a minimum of one man-hour per acre per irrigation.

6. Water-cooled gasoline power units are using an average of 0.15 gallon of fuel per brake horsepower required each hour. Properly applied power units in good condition will operate more efficiently. Diesel power units are consuming an average of 0.08 gallon of fuel per brake horsepower each hour.

This study clearly demonstrated that each farm presents a wide variety of problems which must be solved in various ways. The simple fact that every farm and farmer is different precludes the possibility of being able to go into a department store and purchase a "package sprinkler unit" that will meet the farmer's needs.

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EVALUATION OF SPRINKLER IRRIGATION SYSTEMS IN NORTHERN UTAH

Jay M. Bagley and Wayne D. Criddle

Introduction

FOLLOWING the availability of lightweight aluminum tubing in quantity, irrigation by sprinkling has expanded rapidly in the United States as well as other areas of the world. Quick couplers, better pumps, and more dependable power units and power supplies have also contributed to the increased use of sprinkler irrigation. Future land developments will probably be more favorable to sprinkler irrigation since many of the areas best suited for surface irrigation have already been developed. Sprinkler irrigation can be an efficient way of applying water, and as water supply becomes more and more a limiting factor, more efficient methods for its use must be employed.

Because of its relative newness, its rapid growth, and its esthetic appeal, sprinkler irrigation has received much publicity. Advertising has cited the tremendous savings in water, labor, and investment together with increased quality, yield, and profits as a result of using sprinkler irrigation. It is doubtful that the plant knows or cares how it gets its water as long as it can have it where and when required.

Any method of irrigation—surface or sprinkler—which permits the following criteria to be met is a satisfactory method:

1. The right amount of moisture must be stored in the root-zone soil where it can be readily utilized by the crop as needed.
2. There must be no damage to the soil structure nor reduction of soil fertility.
3. There must be no unreasonable waste of water, land, or labor.

All common crops can be successfully irrigated by sprinkling under normal climatic conditions. While until recently the bulk of sprinkler irrigation systems in the United States were found in the West, the numbers are rapidly increasing in the humid areas of the country to supplement natural rainfall. Many areas have what appears to be ample annual rainfall, but in most cases, the rainfall does not come at the right time to produce the best possible crop.

Many farmers have attempted to reduce these weather risks in the production of crops, realizing that even in comparatively wet years, the detrimental effects of short periods of drought are extremely costly.

Sprinkler irrigation in Utah

Following the national trend, the acreage irrigated by sprinklers in Utah has been expanding rapidly. Indications are that increased use will continue. This method seems to be adapted to all farm crops grown in the state, although in the area studied it is presently being used mostly on hay and grain. Farmers in many of the areas to be served by irrigation projects planned and under construction will find sprinkler irrigation most practical.

There are numerous locations in Utah where the water supply is at some elevation above the land to be irrigated. Such conditions are conducive to sprinkler irrigation. By piping the water to the land enough pressure can be created to eliminate or greatly reduce pumping costs. Many streams are small and difficult to utilize efficiently by other methods. Sprinkler irrigation can provide maximum benefit from such small clear streams.

Sprinkler irrigation will be especially advantageous on some of Utah's newer developments. Irrigation of slopes up to 40 percent is planned on some lands under the Weber Basin Project. Such slopes make surface methods almost prohibitive. While it is possible to provide adequate physical controls to irrigate these steeper lands by surface methods, the distribution system must be much more extensive. This results in rapidly increasing costs. Since application runs must be much shorter and ditches and various controls more numerous, there will be a corresponding increase in costs of farm operations such as cultivation, spraying, and harvesting. The savings resulting from reducing these operations to a minimum are difficult to evaluate, but may be substantial. While costs of sprinkler irrigation may also increase with increased slopes and uneven topography, sprinkler irrigation would not have as great an effect on other farm operation costs.

Many sprinkler irrigators express satisfaction at being rid of furrows. Cost of maintaining furrows is eliminated, and harvesting operations are easier with less depreciation on equipment. Orchard growers have reported less bruising of fruit during hauling when ditches and furrows were absent.

There are many small farms in Utah which do not require the full time of the operator. The complete control, simple operation, and uniform application (all possible without any special skills), will make sprinkler irrigation increasingly desirable for the small acreage being managed primarily on "after-work" hours.

Some difficulty arises in the use of sprinkler irrigation in Utah because irrigation water quite frequently is supplied in rotation by mutual irrigation companies. This method of delivery sometimes forces the sprinkler irrigator to schedule his irrigation the same as if he were using surface methods. A system operated under these conditions must be capable of irrigating all the land in a relatively short period of time with a large quantity of water and then lie idle until the next irrigation turn. This requires not only more equipment but larger equipment and more frequent moves. This means higher equipment and labor costs than if the water could be supplied on a more continuous basis. Canal company officials are usually reluctant to make changes which would allow water delivery to an individual stockholder different from other users. However, many instances are known to the authors, in which canal companies have allotted individuals smaller flows for longer periods of time, and the arrangement has worked to the satisfaction of all.

Purpose of this study

Since purchase of a sprinkler irrigation system requires a considerable investment by the farmer, it is important that he recognize the applications and limitations of this method of applying water in order that he may plan to obtain maximum return on his investment. At the present time, much information sought by farmers regarding the economic advisability of investing in sprinkler equipment is controversial. Careful study of the factors affecting design, operation, and use of sprinkler systems for maximum benefit and greatest economy have not kept pace with the rapid expansion of the sprinkler industry.

Since good design and proper operation are essential to successful sprinkler irrigation, studies were conducted on existing systems in northern Utah during 1953 and 1954 to evaluate their effectiveness and adequacy.

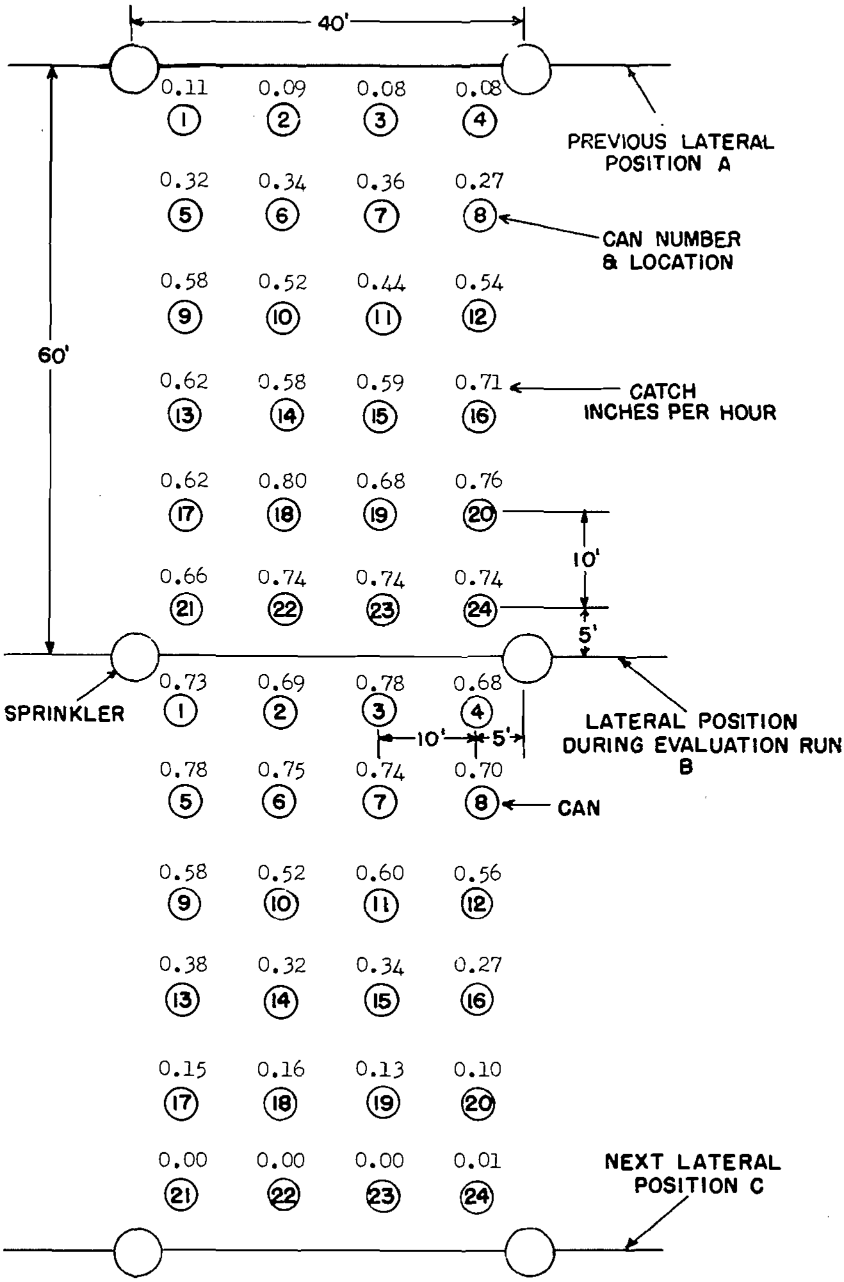

Fig. 1. Layout of cans for measuring the spray from a sprinkler system having a lateral spacing of 60 feet and sprinkler spacing of 40 feet

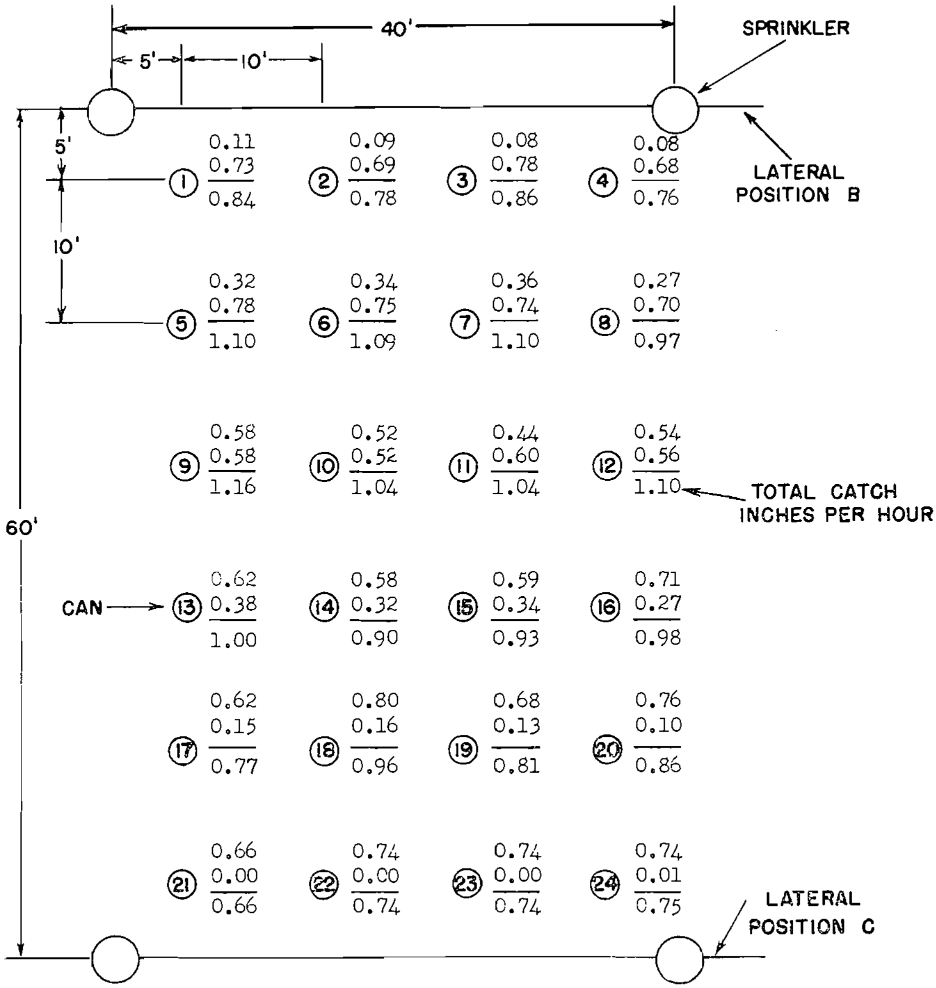

Fig. 2. Method used in superimposing the catch from one operating lateral line to synthesize what would occur if two or more laterals were operating or if the single line were moved and operated in its new position before measuring the catch

The overall objectives of the studies were twofold: (1) through a field study and analysis of the design and operating characteristics of existing sprinkler installations, it was proposed to develop general guides which would be useful to farmers contemplating the purchase of sprinkler systems, and (2) substantiate or improve existing design criteria making possible more economical and satisfactory sprinkler system design.

Obtaining data

Thirty-four sprinkler irrigation systems in Cache, Box Elder, Weber, and Salt Lake Counties were included in

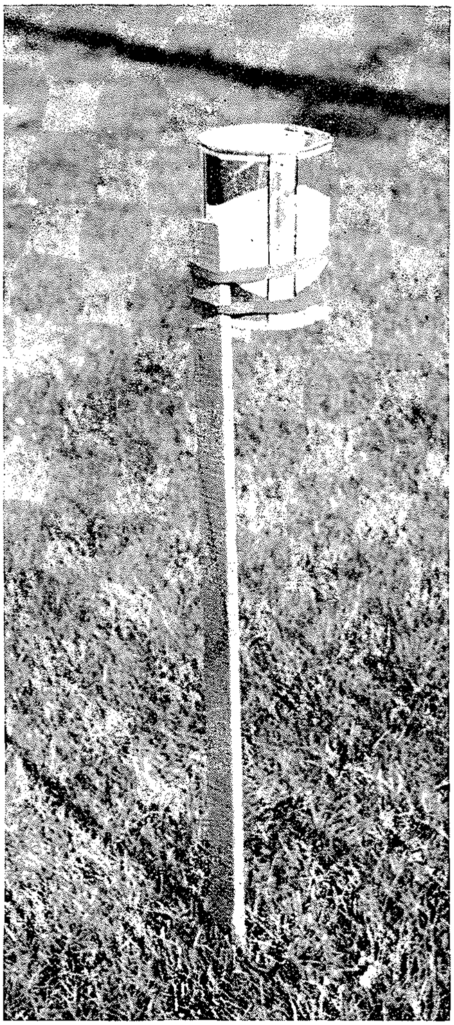

Fig. 3 . Quart oil can supported above crop on stake to catch sprinkler spray

the study, of which 27 had a continuous water supply available. No particular feature of the farm or sprinkler system influenced the selection. However, in the analysis of those factors which may be affected by the nature of the water supply, the data were grouped according to the water supply. To evaluate properly the general performance of each sprinkler system required that certain physical measurements be made.

To measure amounts of water for determining distribution characteristics, efficiencies, and depths applied, collecting cans were placed in a uniform pattern in the wetted area on either side of an operating lateral between two sprinkler heads. A typical layout is shown by fig. 1. Fig. 2 shows how catch in the cans on one side of lateral line was superimposed on the other side to similate the conditions which would exist after the lateral had been moved and operated at the next position. Where foliage would have interfered with the normal catch, cans were attached to stakes above the vegetation (fig. 3). Otherwise, they were placed on the ground. Catch in each can at the end of the test was measured with a graduated cylinder.

Air temperature and humidity were measured at the beginning and end of each test. A hand turbine ventilated

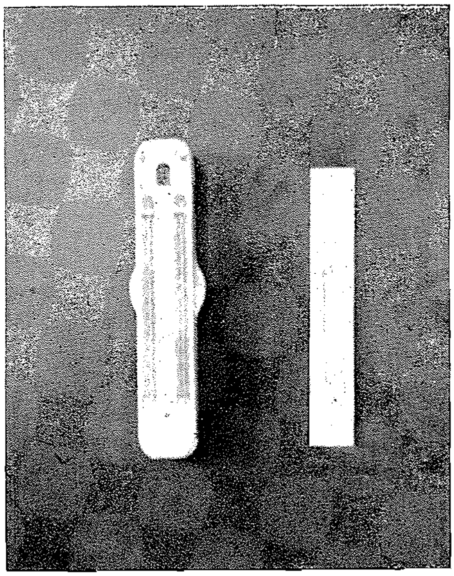

Fig. 4. Hand ventilated psychrometer used to measure relative humidity

Table 1. Adequacy of sprinkler systems investigated in northern Utah having continuous water supplies available

Soil texture	Systems capable of meeting peak water needs of crops									Systems incapable of meeting crop needs			All systems		
	Completely as operated			Within 75 percent, as operated			Within 75 percent if operated properly								
	# of systems	Acres irrigated	% of total	# of systems	Acres irrigated	% of total	# of systems	Acres irrigated	% of total	# of systems	Acres irrigated	% of total	# of systems	Acres irrigated	% of total
Fine	2	114	27	3	214	39	4	234	30	7	1055	76	11	1289	60
Medium	1	23	6	1	23	4	4	183	23	2	185	13	6	368	17
Coarse	7	283	67	8	313	57	10	363	47	2	140	10	12	503	23
All soils	10	420	100	12	550	100	16*	780	100	11	1380	100	27*	2160	100
Percent	37			44			59†			41			100		

*One system had soils in each classification.

†Includes systems now operating capable of meeting peak water needs within 75 percent or better. Thus, although 37 percent are fully meeting the needs as operated, an additional 7 percent, or a total of 44 percent, are meeting the needs within 75 percent and an additional 15 percent, or a total of 59 percent of the systems could meet at least 75 percent of the needs if they were all properly operated.

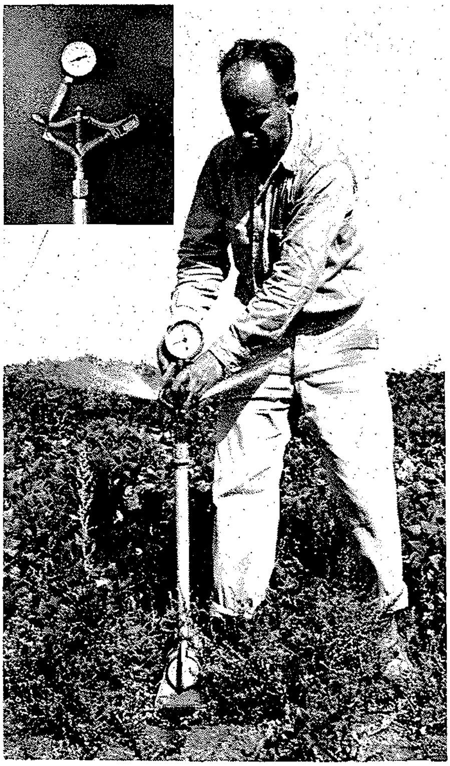

Fig. 5. Method of measuring nozzle pressure with a pressure gage and pitot tube attachment

psychrometer was used for measuring humidity (fig. 4). Wind movement was estimated.

Nozzle pressures were measured with pressure gage attached to a pitot tube. The tip of the pitot tube was inserted into the jet issuing from the sprinkler nozzle and the pressure read directly on the gage (fig. 5). Differences in pressures were measured at the first and last sprinkler along the lateral. Pressures were also measured in the two sprinklers at the test section.

Discharges from the sprinkler jets were also measured. Rubber hoses, 3/4 inch in diameter, were placed loosely over the nozzles and directed the water into a ten-gallon can (fig. 6). The time required for this can to fill was used to compute the sprinkler discharge.

From these basic physical measurements, calculations of application efficiency, distribution efficiency, water losses, and pressure distribution were made. Also, data were obtained from

Fig. 6. Method of obtaining nozzle discharge volumetrically, using 3/4-inch rubber hoses and a 10-gallon can

operators about labor requirements, costs, time of lateral settings, and crops.

An analysis of the sprinkler systems as to their ability to meet the peak water requirement needs is given in table 1. About 40 percent of the systems studied could not fully meet the crop needs.

The sprinkler systems were being used on all types of soil and on many different crops. Data concerning crops being grown under sprinkler irrigation and the acreages of each as found by

U = KF = K(TP)

WHERE: U = MONTHLY CONSUMPTIVE USE (EVAPO-TRANSPIRATION)
K = IMPERICAL COEFFICIENT FOR CROP
T = MEAN MONTHLY TEMPERATURE
P = MONTHLY PERCENT OF DAYTIME HOURS OF THE YEAR
F = MONTHLY CONSUMPTIVE USE FACTOR = TP

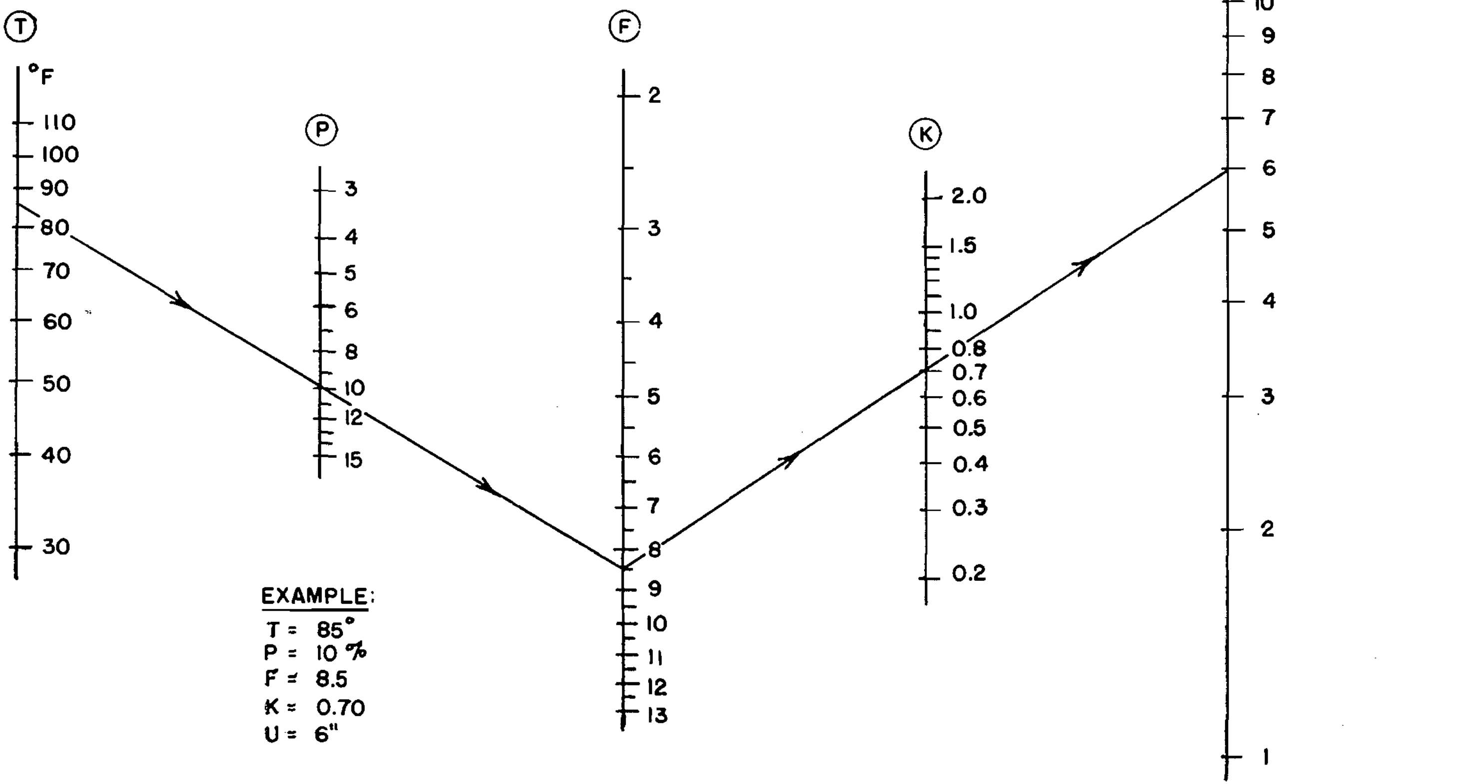

Fig. 7. Nomograph for solution of consumptive use formula

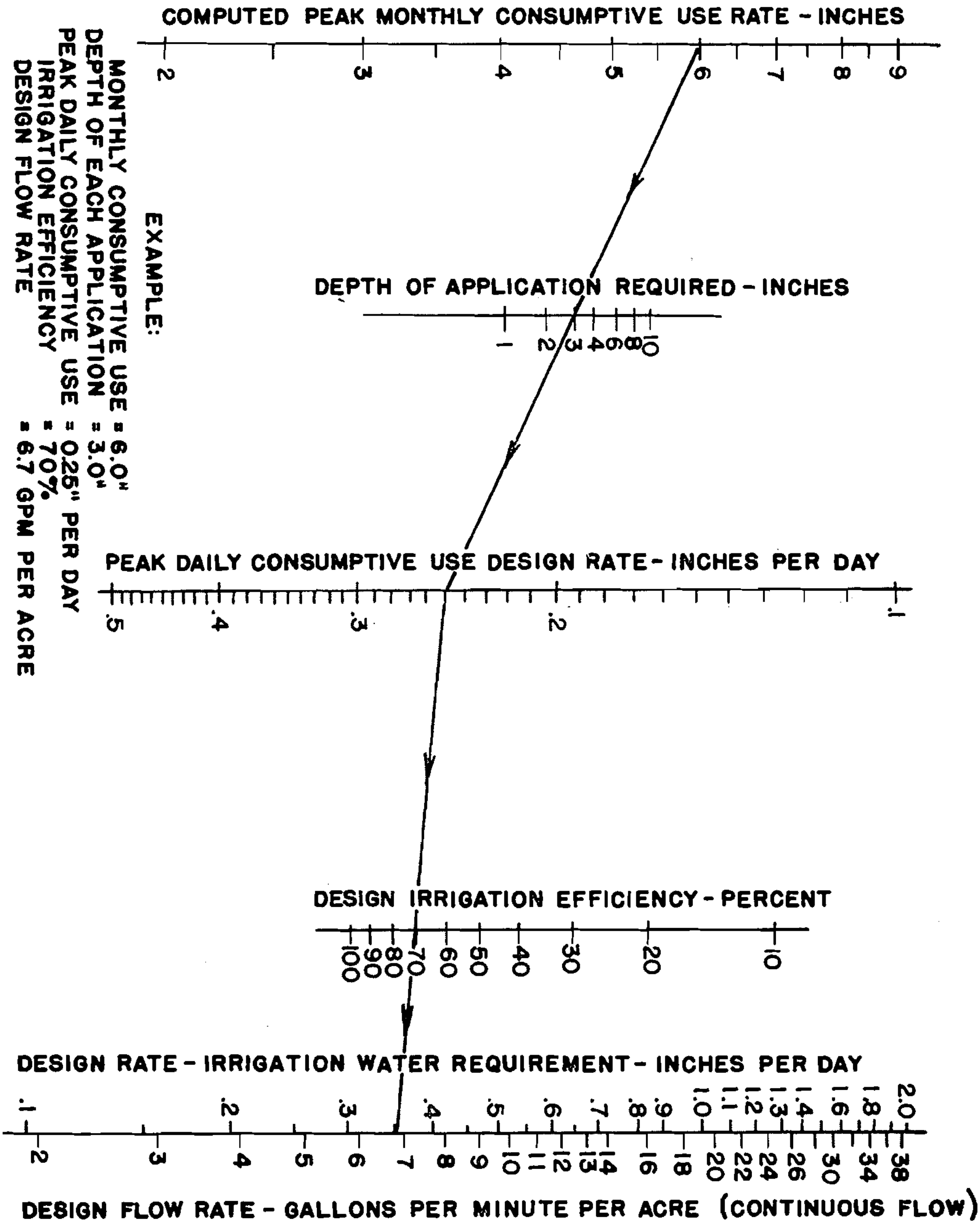

Fig. 8 . Nomograph for computing irrigation requirements for design purposes

Table 2. Crop distribution on various soils irrigated by sprinkler systems in northern Utah

Soil texture	Crop	Acres	Percent Texture group	Percent Total
Fine	Alfalfa	530	41	
	Small grain	745	58	
	Nursery	14	1	
		1289	100	60
Medium	Alfalfa	220	60	
	Small grain	138	38	
	Sugar beets	10	2	
		368	100	17
Coarse	Alfalfa	171	34	
	Small grain	140	28	
	Sugar beets	106	21	
	Peas	51	10	
	Corn	10	2	
	Pasture	10	2	
	Truck	15	3	
		503	100	23
Total		2160		100

this survey are summarized in table 2. Alfalfa and small grains comprised more than 90 percent of the acreage studied. A greater variety of crops was grown on the lighter soils under sprinkler irrigation than on the heavier soils. Alfalfa and grain comprised but 62 percent of the total crop acreage on light soils.

The soil profiles at all test sites were examined visually to a depth of 5 feet. For the purposes of this study, they were given only a general textural classification of coarse, medium, or fine.

Adequacy of the system to meet maximum crop needs was determined from consumptive use of water requirements based on present system operation. These peak use rates were obtained from consumptive use nomographs (Criddle 1953) (fig. 7 and 8) according to the climatic conditions at each system location and to the amount of water actually being applied each irrigation. An irrigation efficiency of 70 percent was assumed which is shown later to be about average for the systems analyzed.

Results of the Survey

This sprinkler irrigation study was directed toward gathering information on equipment and operational costs, system capacities, distribution and application efficiencies, and general sprinkler irrigation practice and performance.

Cost of ownership

Studies in Montana (Monson 1952)

Table 3. Items to consider in comparing costs of sprinkler and surface irrigation methods

Item	Sprinkler method	Surface method
COSTS (fixed)		
Depreciation	On all equipment including wells, pumps, power units, pipe, sprinkler heads, etc.	On wells, pumps, power units, pipe, conveyance and control structures. (No depreciation for land grading but consider under interest on capital investment.)
Interest	On total capital investment for equipment, facilities, and necessary land grading.	On total capital outlay for structures, equipment, facilities, and land grading.
Water supply	Base water charges, purchase of water rights, ditch shares, or storage rights. Construction costs to make supply available. O and M charges.	Same as for sprinkler.
Drainage	Surface and subsurface drainage facilities to remove excess water. O and M charges.	Surface and subsurface drainage facilities to remove excess rainfall and deep percolation from surface irrigation. O and M charges.
COSTS (operating)		
Power	For obtaining water and providing necessary pressure for sprinkler operation.	For pumping if source of supply is not at highest point on farm.
Labor	For moving system and applying water.	For applying water.
Maintenance	Pumping plant, distribution system, silt and debris removal.	Floating land surface, irrigation, structures, ditches, reconstruction of furrows, borders.
BENEFITS		
Returns	Gross return from crops.	Gross return from crops.

indicate that nearly half of the adverse comments of farmers regarding their sprinkler systems was that of high costs. It is possible that in some cases, the high costs were partly a result of such factors as poor layout, poor design, poor equipment, or poor operation of the equipment. Nevertheless, the important consideration of cost cannot be over-emphasized.

The total cost of owning a sprinkler irrigation system is the amortized cost of sprinkler equipment, together with costs of operation. In many instances the annual operating cost will exceed the annual cost for interest and depreciation. Cost figures alone without return figures to compare may be somewhat misleading. The real measure of a system's worth is the difference between costs and returns—or profits. The fact that one system appears to "cost" more than another is not the entire picture. It may also "return" more. This should be kept in mind in any cost comparisons. The various items of cost and return that should be considered in making any evaluation are summarized in table 3.

In addition to items having a direct influence on costs and returns, as shown by table 3, are factors which have indirect influence. Canals and laterals constructed to fit contours or uniform grades often result in odd-shaped fields. Because ditches cannot be crossed and

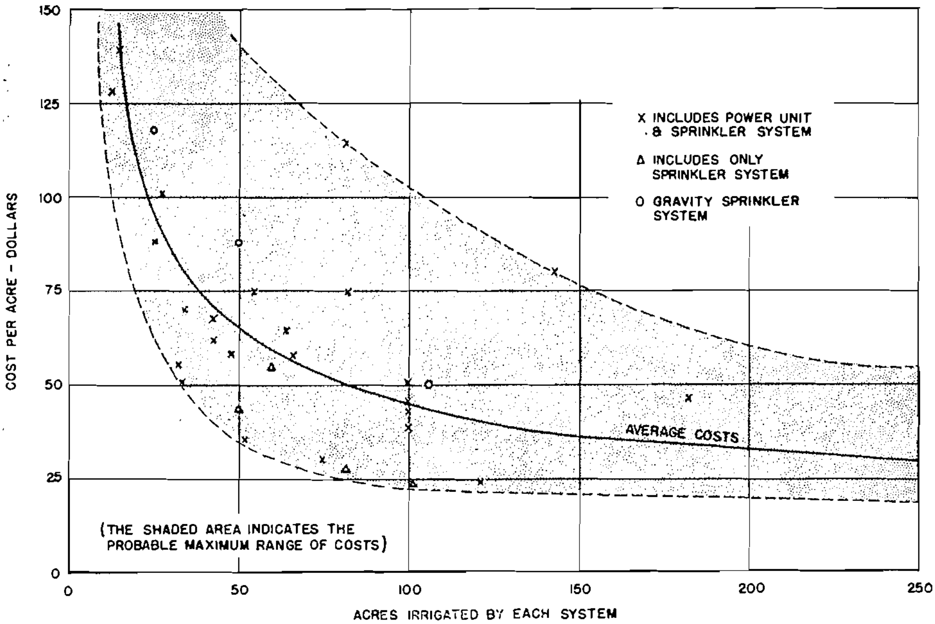

Fig. 9. Relation between initial investment per acre and number of acres irrigated by sprinkler system

fields are irregular; land preparation, harvesting, and tilling operations are made more difficult. Regular-shaped fields greatly simplify farm operations. Sprinkler irrigation will often make this possible where surface methods cannot.

Farm machinery operation and maintenance may be lessened by elimination of furrows and ditches. Their elimination also results in additional land area being brought into production. Ditch-bank-weed problems will also be eliminated.

Soluble fertilizers, although not limited to application by the sprinkler method, can often be applied with labor requirements slightly more than those required for irrigation alone. These plant nutrients already in solution become immediately available to the plant.

Disadvantages such as inflexibility in the use of sprinklers and the inability to make full use of summer precipitation might also be considered. Factors such as these are difficult to evaluate in monetary terms but are usually worthy of consideration when comparing methods of irrigation.

Initial investment. It is generally true that the average initial cost of a sprinkler system per acre will decrease as the acreage covered by the system increases. This relation for northern Utah is shown by fig. 9. These data include costs of some sprinkler systems with and others without power units. The data were insufficient to plot separate curves of each. The shaded area shows the probable range of cost for various acreages covered by a single system. In using such a curve to estimate costs, the higher range should be used if power unit is to be included. The lower range will more accurately estimate costs where the irrigator plans to use a power unit already available or where adequate pressure exists. The curve indicates that the average cost for a sprinkler irrigation system to irrigate 100 acres would be about $45 per acre with an expected maximum of about $80 per acre. Data are insufficient to draw definite conclusions about costs for acreages above 100; however, it appears from this study and others (Monson 1952) that costs per acre do not diminish greatly for systems covering approximately 180 acres or more. It is conceivable that costs per acre might even increase on large acreages if irrigated by only one system.

Average costs for the systems studied in northern Utah seem to rise rapidly for areas smaller than 60 acres. Variations in costs are also much greater for smaller acreages so that it becomes more hazardous to use average figures in making cost estimates.

Cost data for all systems are included in fig. 9. Breakdowns of these costs according to adequacy of the system for meeting the peak irrigation needs of the farm are shown in table 4. A farmer contemplating the purchase of a new sprinkler irrigation system would be better guided by cost figures of those systems which are capable of meeting requirements for maximum crop production than by figures including systems inadequately designed. For this comparison, only those systems having a continuous water supply were analyzed. Some of these costs included power units while others did not. A further breakdown would result in too few data to establish any relation.

Whether or not a system was adequate was determined by comparing the computed safe allowable interval between irrigations with the minimum interval presently obtainable by the system. Dividing the actual depth of water being applied at each irrigation in inches by the computed design consumptive use rate in inches per day, gave an allowable interval in days between irrigations. The minimum possible interval between irrigations is based upon the physical limitations of the system. The total number of lateral moves necessary to irrigate the farm completely is divided by the product of the number of operating laterals times the number of lateral moves each day. This gives the minimum possible interval between irrigations. Consideration must be given to the dropping off or adding of laterals when fields are irregular. Consideration must also be given to various crops and acreages of each since the number of moves made per day will vary — a greater depth of water being applied to deeper rooted crops each irrigation but usually at less frequent intervals.

From a practical standpoint, the best irrigation interval to consider is one somewhat shorter than the computed safe limit. The interval should not, however, be unnecessarily short. With the more frequent irrigations, there may be additional loss of water and soil nutrients. It should also be noted that a safe interval in July is not necessarily a safe interval in May or September. Certain changes in irrigation interval and time of lateral settings will often be found advantageous depending on the crop, its stage of development, and variation in soils. Design capacity, however, must be based on maximum water requirements and minimum safe interval.

The 27 sprinkler systems with a continuous available water supply were grouped into (1) those systems able to meet maximum water requirements of the crops, (2) those systems meeting at least 75 percent of the peak water requirements, and (3) those systems which could have met at least 75 percent of the peak water requirements of the crops had they been operated as designed. Those systems not able to supply 75 percent of the peak

Table 4. Cost data for sprinkler systems having continuous water supply available

Item	Systems meeting peak water needs: Completely as operated	Within 75 percent as operated	Within 75 percent if operated correctly	All systems
No. systems	10	12	16	26*
Avg. cost per acre (dollars)	85	77	71	60
Avg. weighted cost per acre (dollars)	73	61	57	45

*No cost data available for one system in this group.

water requirements could hardly be considered adequate.

Costs in table 4 show some rather interesting trends. Average costs show a steady increase as systems become more adequate. The weighted average cost of the entire 26 systems studied is $45 per acre. However, during periods of maximum water use, these systems could not supply the water needed. Only 59 percent of the systems could reasonably meet the peak demands if operated as designed. In other words, about 41 percent of the sprinkler systems studied are inadequately designed to meet peak water requirements. Of the 59 percent capable, about 15 percent have not been meeting these demands because of improper operation.

A plot of the data in table 4 is shown in fig. 10, and seems to give a rather well defined relation between cost per acre and percent of system adequacy. The higher curve is for a simple average cost of the individual sprinklers per acre, the lower is a weighted average (dividing the total cost of the systems being studied by the total acres being irrigated by these systems). It should be remembered that these figures are based on costs of systems having continuous water supply. Systems not having a continuous water supply (those served in rotation or having only a short supply) would undoubtedly show a different cost relation since capacity requirements of a system vary inversely with the percent of time the system is able to operate. Under an intermittent type of water delivery, the capacity of the sprinkler system would need to be increased. This would, of course, increase equipment costs.

Based on average figures, original investment for sprinkler systems is somewhat lower than figures reported by other states in earlier studies. Assuming costs since World War II have increased rather continuously, the Utah results would be even lower in comparison with other states. Compared to northern Utah's unweighted average of about $60 per acre, Montana (Monson 1952) reports $82, Idaho (Jensen and Bevan 1951) $83, Colorado (Code and Hamman 1950) $88, and Oregon (Becker 1953) $116. In all cases, there is a considerable range in actual costs. Costs in Utah ranged from $14 to $140 per acre. Montana data show a range of from about $12 to $284 per acre, Colorado costs ranged from $25 to $156 per acre, and Oregon reports a range from $30 to $504 per acre.

Systems in the lower range are believed to be inadequate to irrigate properly the acreage reported. The more expensive sprinkler systems are probably capable of irrigating more acreage than that for which they are used and may contain many unusually costly features. The average cost for Utah systems which were adequate in

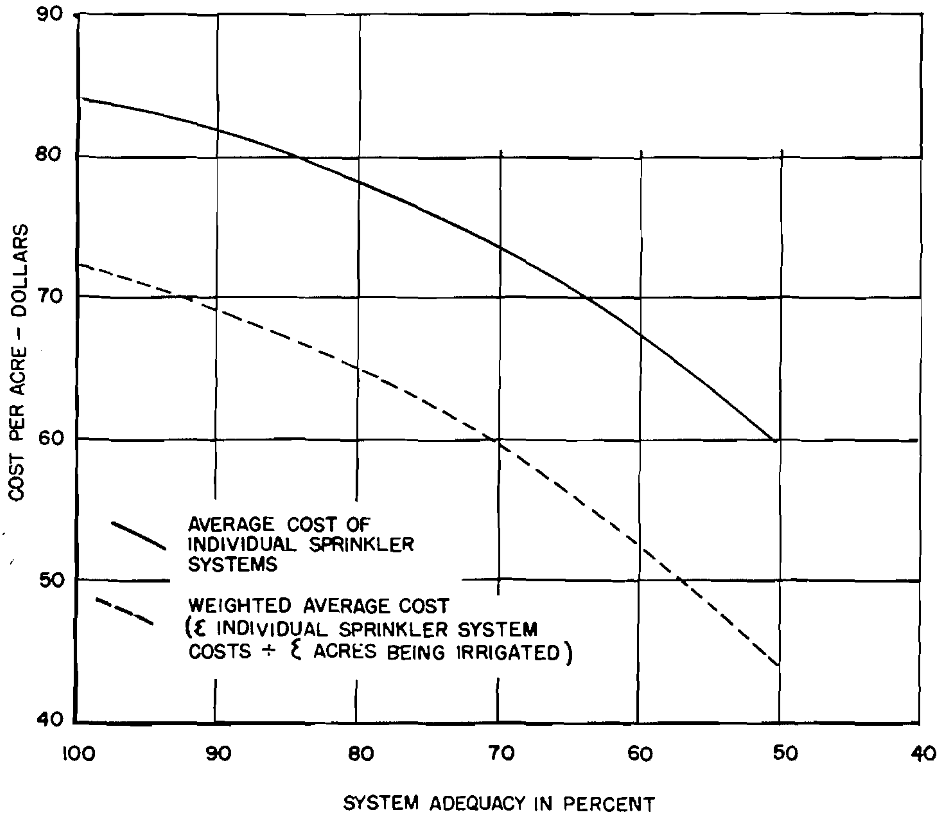

Fig. 10. Relation between initial cost and adequacy of system

all respects was more nearly comparable to average costs in other states.

Costs of investment can be expected to vary greatly depending on shape and lay of the land, acreage covered, source and location of the water supply, elaborateness of system, and other factors. However, under 1954 prices, the average farmer in northern Utah will have to figure on spending $75 to $85 per acre for an adequate system.

Operating costs. With surface methods of irrigation, the initial outlay for land preparation and for the farm irrigation systems is the major cost consideration. With sprinkler irrigation systems, the initial cost may be most important only where pressure can be supplied by gravity from a water source at higher elevations. The annual cost of operation of a sprinkler system will often exceed the annual depreciation cost of the equipment. Thus, costs of operating a sprinkler irrigation system certainly cannot be ignored.

Annual operating costs include all seasonal costs for labor to apply the water, fuel or energy, system maintenance, repair, and replacement.

Labor requirements

While labor is one of the most important considerations in sprinkler system design and operation, it is also one of the most difficult to evaluate. Labor costs vary with many factors such as the efficiency of the operator, soil type, topography, height and density of the vegetation, and pipe size, length, and manner of coupling. They vary also with the system design and layout. This includes such factors as depth of water applied each irrigation, length of time allowed for each lateral setting, and the distance between lateral moves.

Moving sprinkler equipment is not a particularly arduous task, since laterals are made of light metals. It is rather distasteful, however, in tall heavy foliage and on fine textured soils which dry off slowly. Frequent interruption of other farm tasks to make lateral moves is also objectionable. Unless these interruptions can be limited, efficiency of overall farm operation will be impaired.

Interviews with farmers revealed that few of them hired labor specifically for moving and operating sprinkler systems. Usually these jobs are integrated into the farm work done by the owner, his family, or regularly employed help. Of those owners interviewed, 10 thought labor was decreased by sprinkling, 7 reported increased labor requirements, 10 found labor requirements about the same as for surface methods, and 6 gave no comparison since their land had not been previously irrigated.

From the information received from farmers during this study, little difference can be shown between costs for labor for sprinkler or surface methods of irrigation. Labor studies in other states comparing surface and sprinkler irrigation have shown that, although highly variable, average labor requirements for both methods are essentially the same. Therefore, the owner who is hiring labor would pay for about the same number of man-hours regardless of the method used.

The average labor requirement for northern Utah was about 1⅔ man-hours for each lateral setting. If weighted according to irrigated acreage the requirement is reduced to approximately 1½ man-hours reflecting a slightly more efficient utilization of labor on larger farms. The average rate of application on all farms was almost ½ inch of water per hour and the average lateral set time was 5½ hours. Since an average of about 1⅔ acres were covered to a depth of a little more than 2½ inches by each lateral setting, some 4 acre-inches were applied at each irrigation. Thus, the labor requirement for each irrigation (lateral setting) averaged about one man-hour per acre or 0.4 man-hours per acre-inch applied. Two factors were found to cause the greatest variation from this average value. They should be considered when estimating labor requirements for any specific instance.

1. More frequent irrigations resulting from shorter times of lateral set will increase labor requirements.
2. The smaller the area covered at each lateral set the more labor will be required per unit depth of water applied.

Therefore, if a lateral set time is used which exceeds the average of 5½ hours found in this study, it will probably reduce the average labor requirement of 0.4 man-hour per acre-inch. The data indicate that labor may be decreased as much as 40 percent in extending a 5 hour set to a 10 hour set, assuming the same area and depth of application in each case. This may be partly attributed to the fact that water would have to be applied twice as fast for the 5 hour move. Greater capacity and larger pipe sizes would be required. Also, water applied at a faster rate for a shorter time may result in a surface that is wetter and more difficult to walk on.

Another serious disadvantage to short "set times" is the constant interruption of other farm work to make the lateral changes. Longer times of set can often be worked in as a "chore." They can be better integrated with other farm activities. If individuals are employed specifically for irrigating, and if soils, topography, and other conditions are such that higher application rates are permissible, then more frequent moves may not be objectionable. On the other hand, if the owner personally does the irrigating along with other necessary farm tasks, then longer sets appear to be more desirable. This situation predominates in Utah.

The trend of a decrease in labor for an increased area of coverage at each set was shown to be related primarily to lateral spacing rather than length of lateral. Although there were insufficient variations in lateral spacings studied in northern Utah to establish a definite relation, it appears that labor saving would be almost inversely proportional to the increase in spacing.

Comparing Utah's labor requirement of approximately one man-hour per acre per irrigation or 0.4 man-hour per acre-inch applied, Montana (Monson 1952) reports labor requirements of 1.5 man-hours per acre per irrigation for grain and hay. Jensen and Bevan (1951) in Idaho indicate an average labor requirement of 0.9 man-hour per acre per irrigation. Oregon (Becker 1953) reports an average for all crops of 0.59 man-hour per acre-inch of water applied or 1¼ man-hours per acre per irrigation. For lateral moving only, the Oregon requirement was 0.47 man-hour per acre-inch or approximately one man-hour per acre per irrigation.

Time necessary for travel enroute to and from the system, for moving portable mainlines, for moving equipment from one field to another, and for maintaining sprinkler equipment in good operating condition was not included in all cases. Therefore, the labor requirement figures as determined by this survey may be somewhat low. They are probably more typical of systems having permanent mainline or mainlines that are moved infrequently. Lateral moves would therefore constitute practically all the labor requirement as reported herein. Generally, more time should be allowed for completely portable systems. Also, additional time will be required to flush lines and clean clogged sprinklers, unless special precautions are taken to prevent foreign material from entering the system when surface water supplies are used.

Fuel requirements

Fuel costs for power to provide the necessary pressure for sprinkler irrigation will vary with several interrelated factors. Among them are type of fuel used, efficiency of the pumping unit, total pumping head, and length of the irrigation season. Water-cooled gasoline engines are most commonly used in Utah. Several of the gasoline powered systems studied, however, have recently changed to other fuels or are contemplating converting to other fuels such as diesel or propane. At present the cost per gallon of diesel fuel to most farmers is approximately 60 percent of the cost of gasoline. Comparison of tables 5 and 6 shows that approximately 35 percent more water can be pumped by using a gallon of diesel than from an equal volume of gasoline. The lower power production from gasoline per unit volume, coupled with its higher cost, makes it about 2½ times as costly as diesel fuel. However, the intial cost of a diesel engine is more than twice that of a gasoline engine of equal power and any repairs are also more costly. Selection of the most economical type of power depends not only upon economy of fuel consumption but also on such factors

Table 5. Fuel, oil, repair, and replacement requirements for systems having water-cooled gasoline power units

Farm number	System capacity	Total dynamic head	Time operated per year	Fuel consumption	Water delivered per gal. of fuel	Amount of lubricants used per 1000 hours of operation	Annual replacement and maint. in terms of init. invest.
	ac. in./hr.	feet	hours	gal./hr.	acre-inches	gallons	percent
2	0.58	106	2160	1.0	0.58	20	0.6
4	0.50	116	720	2.0	0.25	5.5	1.2
8	1.26	102	1200	2.0	0.63	17	0.6
9	0.45	97	1180	2.0	0.22	7.5	11.3*
12	1.26	114	1800	2.5	0.50	7.5	2.5
14	1.78	121	840	5.0	0.38	18	0.8
15	1.00	116	800	2.5	0.40	22.5	6.8
18	1.08	88	930	2.0	0.54	19	0.7
20	0.67	138	1050	1.7	0.39	12.5	1.4
21	0.96	102	600	2.0	0.48	12.5	- †
22	0.84	119	825	2.0	0.42	12	4.7
28	0.77	65	1120	1.3	0.63	21.5	2.1
29	0.58	96	360	2.5	0.23	19.5	- †
30	0.61	105	1080	2.0	0.30	10	- †
31	0.79	68	540	1.5	0.53	-	
33	0.61	103	1480	2.0	0.31	7.5	- †
34	0.55	90	1100	2.0	9.28	7.5	- †
Average	0.84	103	1046	2.1	0.40	14	

*Burned out power unit.

†Systems operating first year. No costs reported.

as first cost of equipment, depreciation, and ease of handling and maintaining.

Fuel and lubrication requirements as reported by the sprinkler irrigation operator are summarized in tables 5 to 8. Since figures for the air-cooled gasoline and electric power units are for 2 units only, the average values may be of little significance.

The water-cooled gasoline units were delivering from 0.22 to 0.63 acre-inches of water per hour per gallon of gasoline burned with an average of 0.40. Based on average pressures and capacities at which these systems were operating and an average pump efficiency of 70 percent, this represents a fuel requirement of 0.15 gallon per brake horsepower each hour. (Brake horsepower is that power which must be supplied to the pump drive shaft.) Gasoline engines in good condition are expected to use no more than 0.11 gallon per brake horsepower each hour (Israelsen 1950.) This would indicate that the average water-cooled gasoline power unit being used for sprinkler irrigation in northern Utah is wasting approximately one gallon of fuel in four because of low operating efficiency.

The diesel units appear to be operating more satisfactorily than the gasoline units. The average diesel unit is consuming about 0.08 of a gallon of fuel per brake horsepower expended each hour. Thus, if 20 horsepower must be delivered to the pump, the expected fuel consumption would be approximately 1.6 gallons per hour.

Table 6. Fuel, oil, repair, and replacement requirements for systems having diesel power units

Farm number	System capacity	Total dynamic head	Time operated per year	Fuel consumption	Water delivered per gal. of fuel	Amount of lubricants used per 1000 hours of operation	Annual replacement and maint. in terms of init. invest.
	ac. in./hr.	feet	hours	gal./hr.	acre-inches	gallons	percent
1	1.80	112	2500	3.0	0.60	15	6.2*
4	0.49	116	720	1.5	0.33	5.5	1.2
5	1.09	136	1200	1.8	0.62	20	0.8
16	1.09	96	900	1.4	0.78	17.5	6.5*
17	0.45	123	800	0.8	0.60	12.5	1.4
26	1.44	118	1000	1.5	0.72	20	1.7
32	0.67	105	1080	1.0	0.67	7.5	-†
33	0.61	103	1480	1.0	0.61	10	-†
Average	0.96	114	1210	1.5	0.62	13.5	

*Burned out power unit.

†Systems operating first year. No costs reported.

Diesel units in good condition can operate on about 0.07 gallon of fuel per brake horsepower per hour.

The average fuel consumption of the two air-cooled gasoline units was approximately 0.12 gallon per brake horsepower per hour which is satisfactory. But, since only two air-cooled gasoline units could be included, any comparison with the operating characteristics of the water-cooled gasoline units should be made with extreme caution. Ordinarily fuel consumption in air-cooled units is just as high as water-cooled and the engines are usually shorter lived.

Energy required for the two electric powered units is shown in table 8. The average energy requirement of 1.04 kilowatts per water horsepower each hour is good performance.

There was considerable variation in required amounts of lubrication reported. Water-cooled gasoline units were using from 5½ to 22½ gallons in 1000 hours of operation with an average of 14. This figure is supposed to include all oil changes and additions to the power unit. Based on the composite use of all water-cooled gasoline units, and assuming a pump efficiency of 70 percent, this represents an aver-

Table 7. Fuel, oil, repair, and replacement requirements for systems having air-cooled gasoline power units

Farm number	System capacity	Total dynamic head	Time operated per year	Fuel consumption	Water delivered per gal. of fuel	Amount of lubricants used per 1000 hours of operation	Annual replacement and maint. in terms of init. invest.
	ac. in./hr.	feet	hours	gal./hr.	acre-inches	gallons	percent
10	0.97	85	1200	2.0	0.48	15.5	2.6
13	0.72	150	300	2.0	0.36	40	1.5
Average	0.85	118	750	2.0	0.42	22.5	2.0

Table 8. Energy, oil, repair, and replacement requirements for systems having electric powered units

Farm number	System capacity	Total dynamic head	Time operated per year	Fuel consumption	Water delivered per gal. of fuel	Amount of lubricants used per 1000 hours of operation	Annual replacement and maint. in terms of init. invest.
	ac. in./hr.	feet	hours	gal./hr.	acre-inches	gallons	percent
3	1.60	170	1500	1.03	0.05	-	0.8
23	1.00	100	800	1.05	0.08	-	1.1
Average	1.30	135	1150	1.04	0.06	-	1.0

age use of one gallon of lubricant for every 1015 hours of operation per brake horsepower. Thus, a water-cooled gasoline unit delivering 20 brake horsepower would require approximately 20 gallons of lubricants per 1000 hours of operation.

Under average conditions of diesel operation, one gallon of lubricant is required for each 1340 hours of operation per brake horsepower. Thus, a diesel unit delivering 20 brake horsepower would require about 15 gallons of lubricant per 1000 hours of operation. Contrary to general conditions, water-cooled gasoline engines were using greater quantities of lubricants than diesel engines.

The average requirement for the two air-cooled gasoline units is much higher using one gallon of lubricant in every 580 hours of operation per brake horsepower. For an air-cooled gasoline unit delivering 20 brake horsepower, approximately 34 gallons of lubricant would be required per 1000 hours of operation.

No figures were reported for lubricant requirements of electric driven pumping units, but requirements are normally low being but one-fifth of those required for units using other fuels.

Replacement and maintenance

Costs of replacement and maintenance reported include maintaining the pumping plant as well as the piping system. These costs are reported as annual costs in percentage of initial investment. A wide variation exists here. None of the systems had been in use more than six irrigation seasons. Many systems had not been used one complete season when the survey was made. Actual repair costs reported for sprinklers, valves, and other fittings under normal wear was low. In nearly all cases, repair and replacement costs resulted from accidental damage through handling. Therefore, the amount of repair and replacement that a sprinkler irrigator will find necessary will depend largely on how carefully he will handle and store his equipment.

Most systems reporting unusually high annual costs of replacement and maintenance had costly repairs on their power units. Except in cases where improper engine selection results in overloading from the beginning, these costs can be largely eliminated by the use of safety devices. Where constant attendance cannot be given an engine and pumping unit, safety devices are essential. Such devices shut the engine off should the water temperature become too high, the engine oil become too low, or the pump lose its prime. None of the systems for which burned-out engines were reported had taken these safety precautions. It appears that omitting those systems having unusual repair or replacement costs because of burned-out engines, would result in an annual repair, replacement, and maintenance cost of about 2 percent of the initial cost.

System capacity

The required capacity of a sprinkler system depends on the number of acres irrigated, the maximum depth of water to be applied during each irrigation, the frequency of irrigation, and the number of hours of operation during a 24-hour period. Required capacity is also effected by system layout. This factor is frequently overlooked in estimating required capacities. Irregular-shaped areas will require greater design capacity per unit area than will a square or retangular shape. For rectangular areas all of the sprinkler equipment can be utilized all the time. It is impossible to utilize all the equipment all the time on tracts of irregular shape. Sufficient equipment and capacity must be provided to meet the conditions when lateral settings are longest. For the settings requiring the shorter lateral lengths, part of the equipment will not be used and the flow will be less than the requirement determined from averages of depth, area, and operating time alone. To make up for this, the system must be able to supply an above average flow of water when all the equipment is in use.

A rule of thumb value often used in the United States to estimate water requirements for sprinkler irrigation is that a continuous flow of 6 gallons per minute be available for each acre to be irrigated. This amount is short for the average system in northern Utah as shown in table 9. Undoubtedly, the factor most responsible for this increased requirement is that most of the sprinkler systems are being used on irregular-shaped fields. Only 5 of the 27 systems were operating on lands such that lateral lengths could be kept uniform and all equipment in use at all times that the systems were operated. The other 22 systems had varying degrees of irregularity requiring use of varying lateral lengths to irrigate the land.

As shown in table 9, those systems capable of adequately meeting allowable irrigation intervals were actually designed to deliver 10.9 gallons per minute per acre.

The average weighted capacity of those systems which could come within 75 percent or above of meeting maximum crop demands if operated correctly was 9.6 gallons per minute per acre. The average of all systems, 5.5 gallons per minute per acre, was significantly less. Those systems able to meet allowable irrigation interval requirements ranged in capacity from 6.3 gallons per minute to 28 gallons

Table 9. Design capacities of systems having a continuous water supply

Average	Systems capable of meeting peak water needs			
	Completely as operated	Within 75 percent as operated	Within 75 percent if operated correctly	All systems
No. of systems in group	10	12	16	27
Capacity (gpm per acre)	13.7	12.8	12.0	8.7
Weighted average capacity (gpm per acre)	10.9	9.9	9.6	5.5

per minute per acre. The system having the 28 gallons per minute per acre capacity could cover the designated area in one half the time allowable even though the area was of irregular shape. The system having the 6.3 gallons per minute per acre capacity had no reserve at all and was being used on a regular-shaped area.

It appears that under the average northern Utah conditions, a capacity of approximately 10 gallons per minute per acre will be required. If a farm is of regular shape and the farmer is willing and able to operate his system almost continuously, this requirement can be materially reduced. On the other hand, if the irrigated acreage is of irregular shape and the system is only operated a portion of the time, then capacity requirements should be greater.

The average capacity as determined above is based on a cropping pattern containing about 42 percent alfalfa and 35 percent grain with the balance in various other crops.

Irrigation efficiencies

One of the more important factors affecting the water requirement for any irrigation system is the irrigation efficiency. Water application efficiency, defined as the ratio of the water stored in the soil root zone and utilized by the crop to the water delivered to the field, is the commonly used measure of irrigation practice. However, application efficiencies may be high and irrigation practice poor if the water applied is not uniformly distributed throughout the field and the root zone of the soil. For this reason, application efficiency and distribution efficiency are treated separately in this report and then combined to give an overall sprinkler irrigation efficiency.

Application efficiency. "Application efficiency" as used in this study, is the ratio of the amount of water reaching the ground surface as measured by the sampling cans to the amount being discharged from the sprinkler nozzles. Methods for making these measurements were described in an earlier section. If there is no loss of water by surface runoff or deep percolation, application efficiency, as thus defined, gives an indirect measure of water losses by wind drift and evaporation. While these losses do not represent a great percentage, they are important to consider and should be held to a minimum. Since costs of applying water by sprinkling are relatively high, any wastes represent an economic loss.

Evaporation from sprinkler spray while still in the air was shown by Christiansen (1942) to be about 2 percent providing the spray is not broken up into fine mist which may drift away. The greater portion of the evaporation loss will be from wetted foliage and soil surfaces since the exposed surfaces are extensive and water will continue to evaporate for some period of time after the irrigation. However, this evaporation tends to decrease transpiration and may be partially effective in meeting the water needs of the crops.

Among the climatic factors which will affect the efficiency of application are relative humidity, rate of application, and temperature. All these are known to influence evaporation. Sprinkler spacing, operating pressures, and air movement will also affect application efficiencies, but may have a more pronounced effect on the distribution pattern.

Since the evaporative process is affected by temperature and humidity, these factors were studied in relation to their effect on water losses. Water losses would be expected to increase with increased temperature and to decrease with increased humidity. Data from this study indicated that temperature caused an increase in water loss of about 0.01 inch per hour for each 10° F. temperature rise. Air temperature during the series of tests ranged from 45° to 97° F. with all but four tests occurring when temperatures were between 60° and 90° F. The average temperature at the time of the tests was 75° F. with an average relative humidity of 40 percent. Under these conditions, average total measured losses were 0.06 inch per hour amounting to an average of about 11 percent loss or an 89 percent application efficiency. Part of this loss occurs from evaporation after the water has reached the measuring cans.

Recent studies by Frost and Schwalen (1952) directed specifically toward the determination of spray losses, provide a correction factor to compensate for evaporation from cans during test runs. Based on average climatic and operating conditions for the tests in northern Utah the application of this correction factor results in an average loss of 8 percent or an application efficiency of 92 percent.

A nomograph developed by Frost and Schwalen for estimating the evaporation spray loss is shown in figure 11. This was developed from results of some 700 test runs under a variety of climatic conditions.

Since the normal monthly temperatures at Weather Bureau stations in the northern Utah area vary from about 60° to 75° F. during June and July, and the average relative humidity during these two months is about 40 percent, the tests should be indicative of losses that might be expected when sprinkler systems are operated night and day. Should only daylight operation be used, losses would be higher since daytime temperatures are higher and relative humidity is lower.

In the northern Utah tests, the maximum measured water loss of 22 percent occurred when the temperature was 82° F. and the relative humidity was 20 percent. The application rate was only 0.32 inch per hour. From these results it would appear that under average temperature and humidity conditions in northern Utah, if a system applies water at the rate of one-half inch per hour or greater, an application efficiency of 90 percent or more can be expected.

It is logical to assume that the rate of loss to be expected would be essentially the same regardless of the rate at which water is being applied. This being true, the application efficiency would increase with increased application rate. Highest application efficiencies should be obtained when the system is designed to apply water as rapidly as possible without causing surface runoff. Although these data were inadequate to indicate definite relations or trends in this regard, they do corroborate the work of other investigators in this field (Code and Hamman 1950).

No actual measurements of wind velocity were taken and the estimates are not considered to be of sufficient accuracy to determine the effect of wind on application efficiency. South Dakota experiments conclude that relative humidity of the air, the rate of water application, and temperature have considerably more effect on application efficiency than does wind velocity or sunshine during irrigation (Erie *et al.* 1954).

Distribution efficiency. The aim of good sprinkler irrigation is to prevent parts of the field from being under-irrigated while other parts are over-irrigated. Lack of uniformity can result in areas of poor vegetative cover and low production. Distribution efficiency, as the term implies, gives a measure of the ability of a sys-

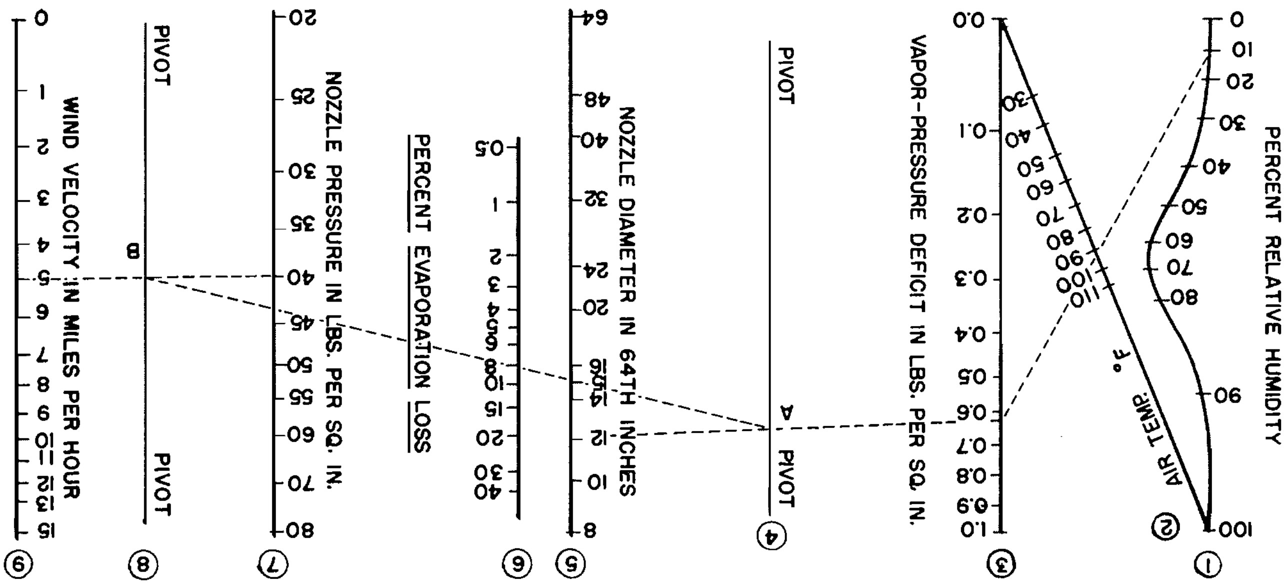

Fig. 11. Evaporation and wind drift losses
Nomograph for determining the spray loss and wind drift for specific weather conditions, nozzle size and pressures.
Example given: The loss is 8.5 percent for 3/16 inch range nozzles operating at 40 psi nozzle pressure with a wind velocity of 5 miles per hour when the relative humidity is 10 percent and air temperature is 90 degrees F. If a 3/16 inch x 1/8 inch sprinkler head were used with spreader pins, a nozzle size one-half way between the 2 nozzles should be substituted which would be 5/32 inch. Without pins the error would be negligible if no correction for the small nozzle was made. (Nomograph by K. R. Frost and H. C. Schwalen, Arizona Agricultural Experiment Station).

tem to apply equal amounts of water to all parts of the area covered. In this study, the measure of distribution efficiency is based on the ratio of the average catch in the 25 percent of the cans receiving the least amount of water to the average catch received by all the cans. This method of measuring distribution efficiency has been used rather widely by the Soil Conservation Service (Pair and Shockley 1956).

Uniformity of water application by sprinkling is affected by pressure at the nozzle, spacing of the sprinklers, and wind movement. Unlike the other factors, wind cannot be controlled but it can be measured so that its influence can be studied. Such studies have been made in recent years by South Dakota (Wiersma 1952), Washington (Molenaar *et al.* 1954), and British Columbia (Wilcox and Swailes 1947). In all cases, winds caused an increasingly detrimental effect on distribution as the velocity increased. However, this harmful effect of wind is lessened with proper spacing of sprinklers and laterals. Studies indicate that if winds are a factor, yet do not prevail from a certain direction, sprinklers should be spaced not more than one-half their diameter of coverage from each other. For prevailing winds, laterals should be laid transverse to the wind and spacing of sprinklers on the lateral line should be reduced to 0.2 to 0.3 of the wetted diameter of coverage. Regardless of spacing, seasonal distribution efficiencies can be greatly improved by offsetting the laterals one-half lateral spacing every other irrigation.

In the various studies of sprinkler irrigation, the relation between wind speed and distribution efficiency has been established. Although wind speeds were only estimated in this study, the trend of poorer distribution with increased wind is evident. The average distribution efficiency, regardless of sprinkler spacing, when winds were estimated to be from 0 to 5 miles per hour, was 78 percent. With winds between 5 and 10 miles per hour, this efficiency drops to 74 percent, and between 10 and 15 miles per hour, to 55 percent.

Most of the systems in the Utah study were using a 40 to 60 foot spacing. As a comparison, Washington studies (Molenaar *et al.* 1954) indicate average distribution coefficients[1] for this spacing of 81 when winds were from 1 to 4 miles per hour, 74 with winds from 4 to 7 miles per hour, and 60 with winds from 7 to 11 miles per hour. In all cases uniformity was improved when spacing was reduced to 40 by 40 feet.

Undoubtedly, the average values of distribution efficiency as determined by this study would be well on the safe side for use in design since those systems not performing adequately would tend to lower the average. For instance, on one farm the sprinkler in use should have been operating at approximately 40 pounds per square inch pressure. The pressure used was 15 pounds per square inch. Under ideal wind conditions this system had a distribution efficiency of 66 percent which could undoubtedly have been greatly increased with proper operation of equipment. Another farm was using an 80 foot move when not greater than a 60 foot move should have been recommended for the sprinkler used. This system was operating at 64 percent distribution efficiency with no wind. Systems so poorly operated result in an efficiency far below what might be expected with proper design and operation.

While there is no question that the effect of wind is more pronounced for

[1]The uniformity coefficient expressed as a percentage is defined by the equation $CU = 100\ (1.0 - \frac{\Sigma X}{mn})$ in which **X** is the deviation of individual observations from the mean value **m**, and **n** is the number of observations.

wider sprinkler spacings, from a practical point of view the selection of spacing will be on the basis of achieving a balance between cost of labor for moving, cost of power, and increased efficiency from more uniform application with closer spacings. Moving pipe 60 feet between lateral settings instead of 80 feet would increase labor requirements approximately a third. This additional labor cost would have to be compared with any possible decreased power costs for closer spacing, and the value of any possible increase in production which may result from better water distribution.

Overall efficiency. In determining system capacity and depths of water to apply, both application efficiency and distribution efficiencies should be considered. The product of the two efficiencies gives an overall system efficiency which would insure that not only sufficient quantities were applied to meet crop requirements but that all parts of the field would receive adequate water. Application efficiency in the northern Utah studies averaged approximately 90 percent. Distribution efficiencies for the most common 40 by 60 foot spacing are about 80 percent or more with winds from about 0 to 5 miles per hour, about 75 percent with winds from about 5 to 10 miles per hour. Most of the areas covered by this survey in northern Utah are not affected by winds greater than 10 miles per hour except for short periods of time. Also, the wind is of a diurnal nature usually blowing only certain hours of the day. With winds no greater than 5 miles per hour overall efficiency for the 40 by 60 foot spacing should be at least 72 percent. For winds consistently greater up to 10 miles per hour, overall efficiency would be approximately 67 percent. Greater spacings, such as 60 by 80 feet, would have lower efficiencies than would the closer spacings. Tests were insufficient on other spacings to make any reliable efficiency estimates but it appears that a 60 by 80 foot spacing under the same climatic conditions as a 40 by 60 foot spacing would have an overall efficiency at least 5 percent lower.

Depth of application

The capacity of a soil to hold readily available moisture for use by the plants is an important consideration in the design of a sprinkler irrigation system. This soil property varies widely. The coarser soils may hold ½ to 1 inch of available moisture per foot depth of soil, medium soils up to 2¼ inches, and fine textured soils 2 inches or more. The root zone depth is not constant either, but varies with crop and stage of plant development. New seedlings require small quantities of water applied frequently.

It is important that the irrigation farmer realize the amount of water that can be stored in the root zone each irrigation. For maximum growth of the crop, it is essential that the entire root zone be utilized. Shockley (1955) concluded that under irrigation, regardless of root zone depth, plants extract about 40 percent of their annual moisture needs from the upper 25 percent of their root zone, 30 percent from the second 25 percent, 20 from the third, and 10 from the lower 25 percent. However, if the lower half of the root zone is not irrigated, yields may be reduced as much as 50 percent.

In addition to its detrimental effect on yields, applying water in an amount less than that required to fill the root zone soil fully will necessarily increase the number of irrigations needed during the season. This will result in increased handling and moving of irrigation equipment and will increase labor costs. Evaporation losses will in-

Table 10. Depth of application per irrigation (gross)

Average	Systems capable of meeting peak water needs: Completely as operated	Within 75 percent as operated	Within 75 percent if properly operated	Average for systems having continuous water supply	Average for all systems
No. of systems in group	10	12	16	27	32
Depth of water applied inches					
Alfalfa	3.6	3.5	3.3	2.8	2.8
Small grain	2.8	2.7	2.8	2.4	2.3

crease since more frequent irrigations mean more evaporation opportunity. Thus, lowered efficiency of application will result, and greater system capacity will be required. This in turn will result in the need for more equipment and energy.

The average depths of water applied to fields studied at each irrigation for the two principle crops, alfalfa and small grains, are shown in table 10. It is significant to note that those systems supplying adequate moisture were applying it in greater depths at each irrigation. In many cases it may be possible, especially on alfalfa, to reduce sharply the number of irrigations required by increasing the depth of each application without causing excessive deep percolation losses. Savings in labor costs would be almost in direct proportion to the reduction in number of irrigations.

Some mention should be made concerning over-irrigation although few of the systems studied in northern Utah show this to be any problem. Loss of water by deep percolation may be more of an economic loss in sprinkler irrigation than under surface methods since it represents wasted pumping and power costs.

Most sprinkler systems in northern Utah are not supplying sufficient amounts of water at each irrigation. This may be partially explained by the desire to keep pumping costs to a minimum. It may be, also, that farmers accustomed to irrigating their lands by surface methods have come to judge the completeness of irrigation by the amount of lateral soakage between furrows. Since the ground surface is completely wetted by sprinkler irrigation, farmers sometimes decide, prematurely, that the soil has been well wetted. Statements from many farmers comparing both methods express the belief that applying water by surface methods affords a more "thorough" or lasting irrigation. In reality this is simply because they apply more water with the surface methods. This is made evident by studies of surface irrigation practices in Davis and Weber Counties, Utah, in 1937 and 1938 (Criddle and Donnan 1951). On farms not affected seriously by ground water, the average depth of water applied at each irrigation for alfalfa was 4.4 inches and on small grains 3.9 inches. This is approximately 35 percent more than is being applied on the alfalfa by sprinklers and about 40 percent more than sprinkler application to small grains in northern Utah. It is quite possible that fewer irrigations per season were required under surface irrigation. The data are not sufficiently complete to show this relation.

Unless soils are shallow or have some restricting layer near the surface or other limiting conditions, better utilization of the root-zone depth can be made by applying water in greater amounts and perhaps less frequently than is being done at present. Thus, while past studies in Utah have shown that the dominant factor contributing to low efficiencies by surface methods was excessive applications of water (Israelson 1944), insufficient applications often contribute to lowered efficiency under sprinkler irrigation.

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