THE EFFECT OF WIND ON THE COST OF IRRIGATION BY SPRINKLERS

by

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ABSTRACT

The effect of wind on the cost of irrigation by sprinklers was evaluated by designing a typical sprinkler system operating under no or low wind conditions, and then comparing its costs with those of alternatives that would possibly be adopted to overcome the adverse effect of high wind on the pattern of water distribution from sprinklers.

After general evaluation of sprinkler systems and establishment of the necessary design criteria, and finding out that the triangular layout does not prove to be more effective than the square one, based on uniformity coefficients, a sprinkler system was designed with a 12 x 12 m. square layout for a typical rectangular farm of 5 hectares in size, using galvanized steel pipes and fittings, and its costs were determined. Then the variations of these costs with kind of equipment, type of system, size of irrigated area, and strong winds occuring assumably for 5 hours during the afternoons in the Bekaa area were evaluated. The initial and annual costs of this system, operating continuously for 22 hours a day or 11 hours per setting, were found to be LL. 9271.23 and LL. 611.00 per hectare respectively. With water being limited and having a value of 0.5 piasters per m^3, the annual cost increased to LL. 713.10 per hectare.

The initial and annual costs increased by 18.1 and 29.5 per cent respectively when aluminum pipes and fittings were used.

Due to relatively low labor cost in Lebanon, it was found to be more economical to use portable sprinkler systems than solid ones where main and laterals are set permanently in the field for one growing season.

Using the same galvanized steel pipes and fittings, it was found that the initial cost of sprinkler system first decreases with the increase of the size of irrigated area up to 12 hectares and then increases. The optimum range, as far as installation cost of sprinkler systems is concerned, was found to be between 5 and 15 hectares. The cost would decrease if the main steel pipes in larger farms were replaced with asbestos cement pipes.

Assuming five hours of strong winds, the annual per hectare cost of irrigation by sprinklers under two alternatives - one with interrupted operation, and the other with continuous operation of the system - were compared with that of the system operated continuously under no or low wind conditions. The annual per hectare cost of the first was higher by 11.2 per cent due mainly to extra equipment cost, and that of the second by 13.6 per cent due mainly to the cost of water loss. With water being limited and having a value of 0.5 piasters per m^3, the annual per hectare costs of the two alternatives were respectively higher by 10.11 and 14.00 per cent than that of the system operated continuously under no or low wind conditions.

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INTRODUCTION

With the increasing demand for water, there is an increasing need for more efficient irrigation, everywhere in the world. One important means of meeting this problem is the use of the sprinklers. Irrigation by sprinklers is the most efficient method of applying water to the soil, under certain circumstances, although not always economically competitive with other methods of irrigation.

Sprinkler irrigation is used on a very small scale in Lebanon today. However, with the development of favourable conditions it might be expected to acquire widespread use.

The major problem with sprinkler irrigation is its high initial cost. A special problem that might influence its introduction into the Bekaa area of Lebanon is the influence of high variable winds on the uniformity of water distribution by sprinklers.

The objectives of this study are:(1) to determine the cost of installation and operation of a sprinkler system under conditions of no or low wind, (2) to determine the effect of high wind on the cost of irrigation by sprinklers under a variety of alternatives, and (3) to make recommendations on adoption of the most economical alternative.

In determining the initial cost of a sprinkler system and the effect of wind on the annual cost of irrigation by sprinklers, it was necessary to use different layouts, pressures, nozzle sizes, types of sprinklers, types of systems, and a variety of farm sizes.

For the rectangular pattern, the 12 x 12 meter spacing determined by Mutayreh (35) was adopted. For the triangular pattern an attempt was made to determine the most efficient layout using the same field data that he had obtained.

The study of variations of pressure, nozzle sizes, and sprinkler types in relation to relative cost was not included in this study because of being a subject large enough to make a thesis by itself.

The prices of equipment were obtained from two companies in Beirut that import both aluminum and galvanized steel products. The effect of each kind on the cost of irrigation was evaluated.

Variation of cost with type of system was determined by designing and comparing the cost of a portable sprinkler system with that of a solid system on a typical farm size of five hectares.

The effect of farm size on the cost of a sprinkler system was determined by comparing the per-hectare-cost of systems designed for farms with areas of 2.5, 5, 10, 20, and 40 hectares each.

The time required for moving sprinkler laterals was determined by averaging the actual time spent by laborers in moving the sprinkler pipes from one setting to another in various farms in Lebanon.

It is hoped that such a study, though limited in scope, would set the pace for more detailed study projects that would help farmers in selecting the lowest cost irrigation method appropriate to their farms.

REVIEW OF LITERATURE

Sprinkler irrigation may be defined as the artificial application of water to the surface of the soil, under pressure, in the form of a spray similar to ordinary rain.

A. Development of Sprinkler Irrigation

Sprinkling, as a method of irrigation, was introduced about the year 1900. Most of the early systems were stationary overhead perforated pipe installations, expensive to install but inexpensive to operate. Introduction of lightweight tubing with quick couplings, in the early 1930's, gave impetus to development of portable systems. This reduced the equipment cost and resulted in an increased number of sprinkler installations. Because of its great ease of operation and high efficiency in the control of amount of water applied onto the soil, this method of irrigation is gaining momentum throughout the world. Its rapid development can also be attributed to the wide distribution of electrical power and efficient pumping units (19).

In the U.S.A. the area irrigated by sprinklers was less than 250,000 acres in 1946, but reached 3,000,000 acres by 1954. In Italy, about 110,000 acres were irrigated by this method in 1950. By the end of 1952 the area so irrigated had increased to 225,000 acres and by 1954 was reported to have reached 515,000 acres. In Israel where most of the land is hilly on the one hand, and water is relatively scarce on the other, maximum utilization of land and water has been achieved by adopting sprinklers as a main irrigation method. In 1954, about 95 percent of the approximately 250,000 acres of land under irrigation were irrigated by sprinklers (34). "According to recent estimates, sprinkler irrigated areas are growing at a rate of 10 percent annually, and are now totalling 2.5 million hectares in the world"(4).

B. Types of Sprinkler Systems

1. Permanent system. A permanent sprinkler system is one where main and lateral pipe lines are burried and other parts are fixed to them and remain so for several years. This system is used mainly in orchards, citrus groves, and nurseries. These installations require higher initial investment, but their operation cost is very low (34). There are many advantages attributable to this type of system, such as the ability to place additional water in light soil area in a given field, being able to turn on the water for short periods of time to cool the upper ground surface when it is required as for lettuce, keeping soil moist for production of No. 1 quality yield of certain crops such as potatoes, protection of frost, and having great saving in labor where labor cost is high (13).

2. Semi-permanent system. A semi-permanent sprinkler system includes burried main lines but portable laterals and sprinklers and fixed pumping plants. Semi-permanent systems are suitable for orchards, permanent pastures, and general crops where the entire farm is to be sprinkled and the field boundaries are fixed (34).

3. Solid system. A solid sprinkler system is similar to a permanent system except that the portable laterals and sprinklers are

not set permanently in the field, but may be moved after any season. This type of system possesses the same advantages listed for permanent system plus its flexibility (13).

4. Portable system. A portable system usually consists of a main distribution line which may be portable or permanent, and one or more portable lateral lines with sprinklers. In a completely portable system all of the pipes and pump would be portable. Movement of laterals can be accomplished either by hand or by mechanical power (40).

5. Travelling sprinkler system. This system is composed of a machine that pumps water from a ditch, while moving at a speed of 1 to 5 feet per minute, and distributes it through large sprinklers mounted on the machine, on land lying on both sides of the ditch (40).

6. Self propelled system. This system consists of large wheel towers carrying the pipes above the ground and moving automatically in a circle around the point where the water is supplied (40).

C. General Evaluation of Sprinkler Irrigation

Apart from the ease of operation, many advantages have been attributed to sprinkler irrigation, among which are the following:

1. Water is applied uniformly. Sprinklers are generally spaced at distances that assure uniform water distribution on the irrigated area (46).

2. Application rate is controlled. Water is applied at rates and in quantities that will meet the soil moisture requirements without producing erosion or drainage problems(6), help leach out nuisable

salts (48), and will not carry the growth stimulating nitrate-nitrogen beyond the reach of shallow roots during the early growth of plants, by deep percolation (15). This may result in higher yield and better quality crops (4).

3. Water loss is reduced. There is an appreciable amount of conveyance losses in surface irrigation which can be reduced by installation of sprinkler systems. The losses estimated by various authorities along a distribution system are shown in table 1.

Table 1. Conveyance losses in irrigation system (22).

Losses in	Experiment carried out by		
	Kennedy	J.H. Ivens	L.G. Carpenter
1. Canal	20%	15%	15 - 40%
2. Distribution system	6%	7%	15 - 40%
3. Water courses	21%	22%	-
4. Wastage on fields	25%	27%	-
5. Total losses	72%	71%	-
6. Actually used for crops	28%	29%	-

In France the new Verdon area irrigated by sprinklers requires a flow of 3,100 m^3 per hectare, while the area under the old system required 10,000 m^3 per hectare (8). In the U.S.A. also great water saving is realized by sprinklers (24).

4. Top soil is undisturbed and tillage costs are reduced (48).

5. Land is fully utilized. No land is wasted for ditches or borders (15).

6. Quality of root-crop is preserved. When root-crops are to be lifted, a light application of water one day before lifting the crop softens the soil, makes lifting easier, and thus reduces crop damage (48).

7. New land becomes productive earlier. No preparatory work is needed (48), steep and porous soil is effectively irrigated by sprinklers (6).

8. Land with irregular topography and shallow soil can be irrigated with little grading and disturbance of top soil (34).

9. Weeds are controlled, with no stream to distribute weed seed (49).

10. Seed germination is assured through light and frequent irrigation (15).

11. Fertilizer application is facilitated. Liquid fertilizers can be applied through sprinkler system without much difficulty (2).

12. Frost is controlled. According to Crowley (14) sprinklers are the surest means to control frost and protect almost all crops from freezing damage.

13. Heat is controlled. Temperatures may be reduced by applying water intermittently over the field to be cooled (14).

14. Labor requirements for irrigation are reduced. Unskilled labor can run the sprinkler system if the owner is able to take care of the engine and pump operation (6).

15. Insect infestation is reduced. Aphids, spiders and mites are especially affected by sprinklers (13).

16. Pests are effectively controlled. Chemicals may be rapidly

applied to the field through a sprinkler system before the pest is able to cause serious damage to crop (48).

17. Easily adapted from one crop to another. On irregular land, shift from one crop to another to meet fluctuations in market demand is easily done by sprinkler irrigation because no change of the land surface is required (4).

Not withstanding all the above listed advantages, the following disadvantages of sprinkler irrigation systems have been mentioned:

1. They have higher capital cost. Comparison of two networks in France; one formed of precast concrete canals with a number of siphons delivering water to plots, and the other with sprinklers, has resulted in great savings in amount of water consumed, but in higher cost for sprinkler irrigation than for surface irrigation. The details are illustrated in table 2.

Table 2. Comparison of cost of sprinkler irrigation with that of surface irrigation (18).

Component	Surface irrigation	Sprinkler irrigation
Discharge	1 lit./sec./ha.	0.5 lit./sec./ha.
Power installed	0.32 hp/ha.	0.75 hp/ha.
Density of network of conduits	79 m/ha.	72 m/ha.
Number of hydrants	1.5/ha.	1/ha.
Cost per irrigated hectare	638 Franc/ha.	750 Franc/ha.

2. They have higher operational costs. Maintenance and operation cost of sprinkler irrigation system in Egypt was found to be L.E.*

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*L.E. = Egyptian Livre = 2.8 U.S. dollars = 8.68 L.L.

20.70 per feddan, while that for surface irrigation L.E. 16.5 per feddan (41).

3. They promote certain plant diseases. Sprinkler irrigation promotes development of mildew in vineyards (16).

4. They require clean water. Water carrying debris and other suspended materials clog the nozzles and prevent proper functioning of the sprinkler system.

5. They necessitate foreign exchange in countries where the systems have to be imported (22).

6. They use oil and spare parts which are difficult to import in periods of war (22).

7. They encounter mechanical difficulty. Sprinklers may fail to rotate, nozzles may clog, couplers may leak and engine may get out of order at critical irrigation period where the whole crop depends on irrigation (31).

8. They are not adapted to areas where continuous water supply is not available. Intermittent flows require either larger systems for which the cost becomes prohibitive (31) or require storage facilities which demand an extra investment.

It should be pointed out that favorable results obtained with sprinkler irrigation in a given area under certain environmental conditions do not necessarily assure achievement of the same results in other situations. The choice between sprinkler and surface irrigation in an area should be based on many factors, such as topography of the land, depth and texture of soil, kind of crop to be grown, economic and engineering aspects of the project and others (45).

D. Effect of Wind on Irrigation by Sprinklers.

Quackenbush and Shokley (39) have reported that wind is one of the main physical limitations for sprinkler use. It distorts the pattern of water distributed by sprinklers and reduces its uniformity. Uniformity of water distribution is greatly affected by variation in the direction and velocity of wind (25).

The criterion employed for measurement of the wind influence on distribution pattern is the uniformity coefficient formula. There are two such defining formulas; the one commonly used by designers of sprinkler systems is (14)

$$Cu = 100 \left(1 - \frac{\Sigma y}{mn} \right)$$

Where:

Cu = Coefficient of uniformity.

y = Difference between individual observations and the mean observation.

Σy = Sum of all the y differences for the test area.

mn = Total of all observations.

m = Mean observation.

n = Number of observation points.

The other used to compare relative distribution performances is (34)

$$U = 100 \left[1 - \frac{\sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}}{\bar{x}} \right]$$

Where:

U = Uniformity coefficient.

$\bar{x}$ = Mean value of x_i

x_i = Volume of water observed in individual can

n = Number of grid points within the wetted area.

Wind also increases the water losses from sprinklers. The effect of wind on sprinkler irrigation losses varies with the climatic conditions such as temperature and humidity. Under low air temperatures and high humidities average losses are negligible for all sprinkler irrigation at low wind velocities, and may approach 5 percent at 10 to 15 miles per hour. Under low wind velocities but moderate temperature and humidities the peak losses are about 4 to 6 percent, and On hot dry days 10 to 12 percent and reach 16 percent with high wind velocities (11).

Intensive studies of wind influences on sprinkler patterns started in South Dakota, British Columbia, and Washington around 1950. Wiersma investigated the influence of wind velocity, wind direction, type of sprinkler head, height of sprinkler above ground, pressure at sprinkler, and sprinkler spacing, and reported his findings in thesis form in June 1952. Korven investigated the influence of wind on uniformity of application from different makes of rotary sprinklers at various spacings and pressures, and reported his findings in 1952. These findings were in agreement with the results of Washington studies mentioned above (33).

The Washington study regarding sprinkler spacings in 1950 showed that the detrimental effect of increased wind velocity becomes less pronounced by using closer spacings. Sprinklers operating under 50 pounds per square inch and spaced 40 feet apart provided higher uniformity coefficient than sprinklers spaced 20′ x 60′ or 40′ x 60′ apart. See figure 1.

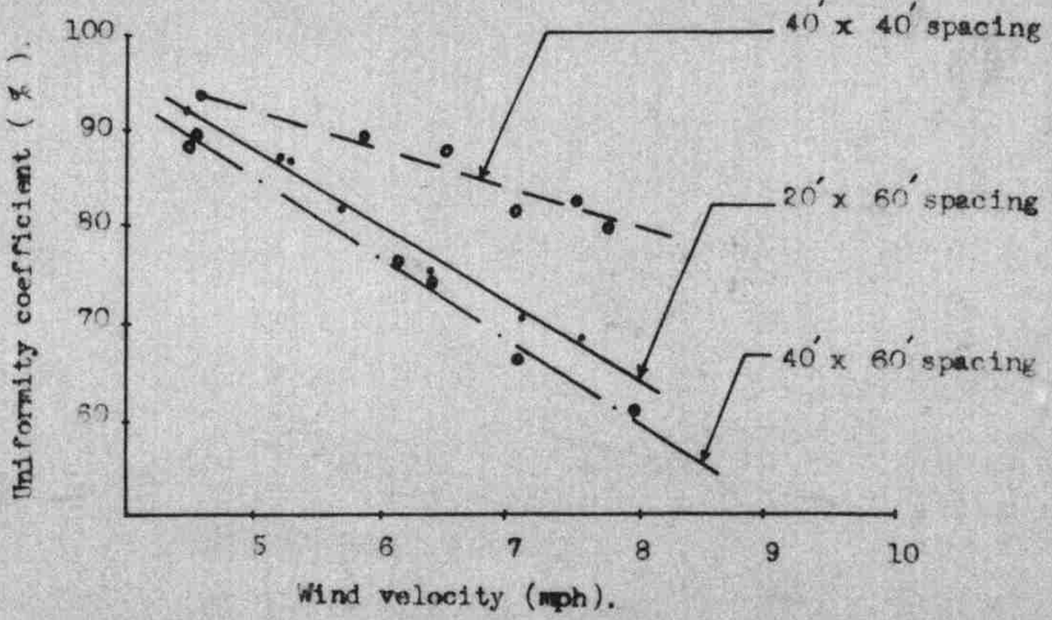


Figure 1. The effect of wind and spacing on uniformity of distribution (34).

Thorne and Peterson (43) have also recommended the use of closer spacings for solution of wind problems. At Inchass in Egypt, wind breaks have been established to eliminate the effect of wind on the uniformity of water distribution from the sprinklers (1).

Mutayreh (35) working on the relationship between wind velocity and spacings in American University of Beirut in 1963, came to the conclusion that a square layout of 12 x 12 m under low wind conditions gives a uniformity coefficient of 93.9 per cent and a rectangular layout of 8 x 10 m under high wind conditions provides 92.6 per cent uniformity coefficient.

McCulloch (31) has suggested the use of triangular arrangements in windy areas rather than the rectangular ones for offsetting the adverse effect of high wind on the distribution pattern. Bauzil (7) has reported that a triangular layout equal to 55 to 60 percent of the wetted diameter of the sprinklers used would generally give a uniformity coefficient much higher than that obtained from square layout with similar conditions. Under low wind conditions and low pressure sprinklers, a 60 x 60 feet triangular or square layout have applied water more uniformly than the 40 x 60 feet rectangular layout (37). Equilateral triangular layout at 60 per cent of the wetted diameter of the sprinklers, used by Selim and Nicola, have given satisfactory results in overcoming the adverse effect of wind on distribution pattern (41).

In 1947, Wilcox and Swailes concluded from their studies that square layout produced higher uniformity coefficients than the rectangular layout, when similar areas were compared (23).

In 1942 Christiansen studied the effect of wind, speed of rotation and spacing of sprinklers upon the distribution pattern. In regard to the effect of wind his conclusion was:

> Although the patterns appear very uneven, the effect of wind on the uniformity of distribution over a larger area, with sprinklers close enough together to provide an adequate overlap, is less serious than unevenness from other causes, such as variation in rate of rotation, because with wind the local areas of high and low concentration .... do not overlap on themselves and produce an exaggerated effect (23).

As a general rule, the sprinkler spacing on the lateral should be from 0.3 to 0.5 of the wetted diameter of sprinkler, and that between laterals should be from 0.5 to 0.7. Sprinkler spacings for winds of 5 to 15 mph (8 to 24 Km/hr) should be reduced to 0.2 - 0.3 of the wetted diameter on the lateral and to 0.5 between laterals (39). The maximum distance between sprinklers on installations in normal wind conditions, that is, when the average wind velocity does not exceed 4 miles per hour, may be 60 per cent of the diameter of coverage of the individual sprinklers (13).

Pressure plays a role on the amount of water lost by evaporation and wind drift, but is not appreciable. With low pressure, water will leave the nozzle in the form of a coarse spray which is less affected by wind than fine sprays. Comparison between fine spray application and coarse spray made in a study by K.R. Frost in University of Arizona (table 3), shows that there is a maximum of 2 percent less loss under low pressure than that under high pressure. On the other hand, the uniformity of water application is much higher under high pressure than low pressure. Thus,it is not advisable to sacrifice uniformity of distribution for a 2 percent saving in spray losses.

Table 3. Comparison of sprinkler irrigation losses between fine and coarse spray (13).

Weather conditions	Peak spray losses in percent	
	Fine spray	Coarse spray
Cool		
Low wind velocity	negligible	negligible
High wind velocity	7 - 10	5 - 6
Warm		
Low wind velocity	4 - 5	3 - 4
High wind velocity	9 - 11	8 - 9
Hot and Humid		
Low wind velocity	6 - 7	4 - 5
High wind velocity	10 - 12	8 - 10
Hot and dry		
Low wind velocity	8 - 10	7 - 10
High wind velocity	14 - 16	12 - 14

Height of riser also has some effect on uniformity coefficient. The tests carried out in Washington in 1950 and 1951, using risers of 14 inches and 26.5 inches, resulted in lower uniformity coefficients for higher risers than those for lower ones. The number of tests being insufficient, they did not make any conclusion in regard to superiority of shorter ones over the longer (33). The length of risers are limited by the kind of crop and conditions of turbulence below which they can not be reduced. A certain length is needed to take out the turbulence, resulting from the change of direction of flow, and reknit the stream before it is discharged from the nozzle. This length depends upon the amount of discharge. The larger the flow, the longer should be the riser.

E. Cost of Sprinkler Systems.

The cost of a sprinkler system is composed of fixed and variable costs. Fixed costs include depreciation, interest on investment, taxes and insurance and any other expenses that have to be paid irrespective of the number of hours a system is operated in a year. The variable or operation costs include labor, fuel, water, repair and maintenance costs and vary directly with the number of hours a system is used. Both depreciation and interest on the investment depend on the initial cost of the system.

1. Initial investment. The initial cost depends upon the source and location of the water supply, the size, shape, and arrangement of the area to be sprinkled, and elaborateness or adequacy of the system (40).

a. Variation of initial cost with adequacy of system. Research carried out in Utah regarding the relation between cost and adequacy of system has shown that the average cost increases as the system becomes more adequate. Under 1954 prices the average cost in Utah varied from $75 to $85 per acre for an adequate system, while the average cost for inadequate system was $60 per acre (5). Other data available indicate that the normal cost was about $125 per acre, and increased as more labor saving devices were added. Permanent systems may cost as much as $500 per acre (20) and often amount to $1000 per acre (40). This high initial cost does not mean that the more adequate the system, the higher is the annual cost. In areas where labor is expensive, a permanent system which reduces labor requirements to a minimum, results in a lower annual cost per unit area than that needed for portable systems (See table 4).

Table 4. Comparison of the annual cost of a permanent system with the cost of a portable one. Both operated 800 hours per hectare(47).

Component	Portable system	Permanent system
Interest on capital	D.M.* 31.50	D.M. 118.12
Amortization	55.80	206.00
Power cost	52.00	52.00
Hand labor	600.00	100.00
Total	D.M. 739.30	D.M. 476.12

*D.M. = Deutsche Mark = 0.25 U.S. dollars.

For this reason, commercial farms in Germany prefer permanent or semi-permanent systems to portable ones (47).

b. Variation of initial cost with the size of irrigated area. Results of studies regarding variation of initial investment with the size of irrigated area are illustrated in table 5.

Table 5. Per acre initial cost of sprinkler systems in the U.S.A.*

Equipment	Tehama County 1951 Forage crops			Ventura, San Bernardino, Orange Counties 1948-49, Citrus		
	Area in acres			Area in acres		
	50	81	165	10	25	57
Well	$39.70	$44.50	$ 4.85			
Pump	32.40	24.00	23.00			
Sprinkler system	79.60	55.60	50.90	$70.00+	$213.00+	$108.00+

*Extracted from table 7 in Sprinkler Irrigation, by Scott (40).
+Detailed breakdown not available; cost may include the pump and well.

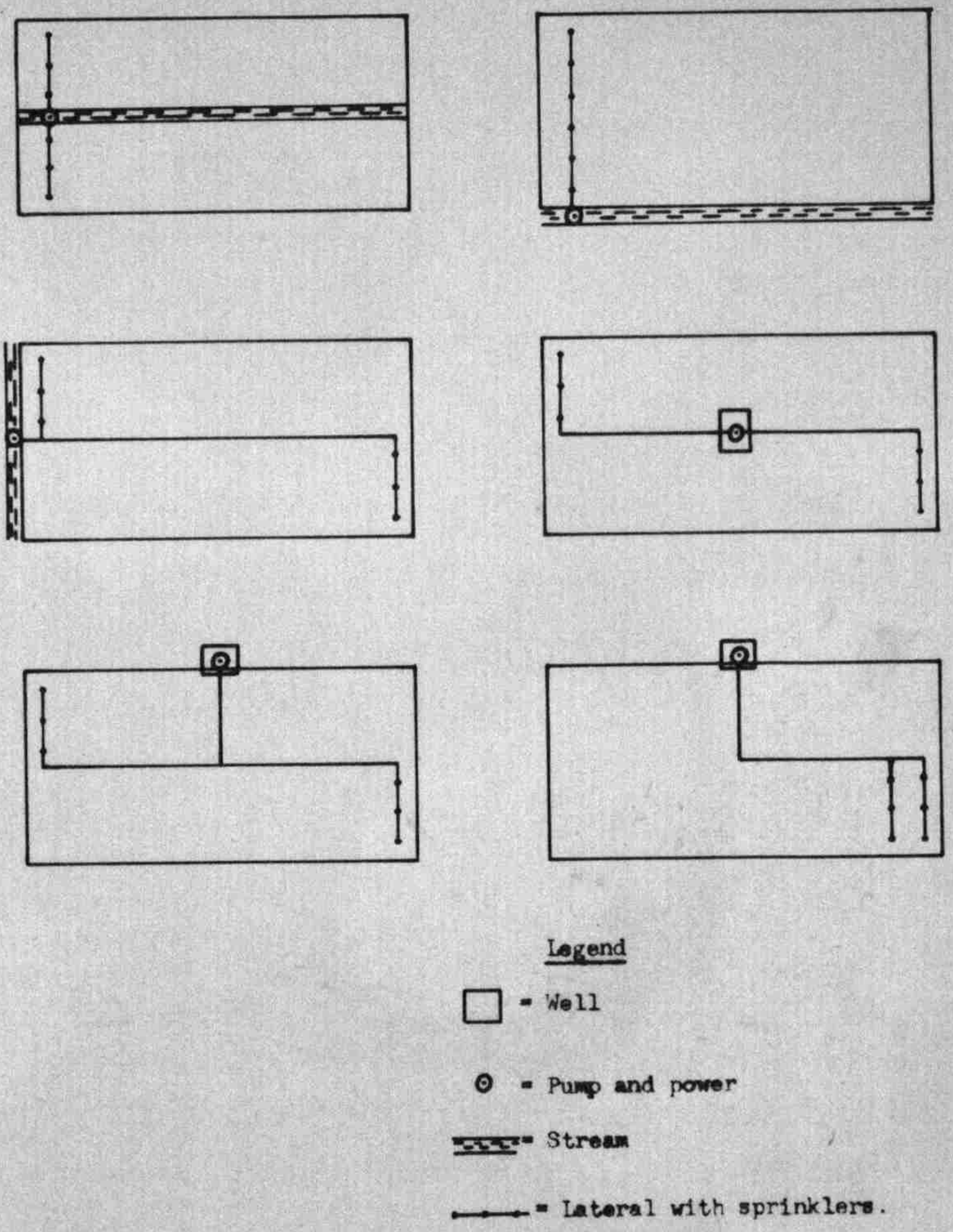
c. Variation of initial cost with shape of the area irrigated. Plots with irregular geometric shapes require branched pipelines for adequate water application which result in higher initial cost of sprinkler system per acre compared with that installed on square or rectangular plots. On plots or zones of land of a width close to the range of the sprinklers, extra branches should be used on the edges of the plot; otherwise two lines will be needed along the narrow strip which doubles the cost of portable pipes and sprinklers (27).

d. Variation of initial cost with source and location of water. General possible cases which may be encountered in regard to the source and location of water for sprinkler use are shown in sketch 1 (34). As can be seen, both the size and length of main and laterals will vary considerably from one case to the other, resulting in similar variation in the initial cost.

The depth to water level in a well is another factor which controls the size of the pumping unit as well as the type of the pump. For deep wells, the installation of the pumping unit will be more expensive than that required for shallow wells.

2. Annual fixed costs. Annual fixed costs of sprinkler irrigation system include the amortization cost of the system plus taxes, insurance, and interest on investment. Various methods are used to figure the amortization of the system. Bonnal has divided the installation into four categories according to the durability of its components and has specified certain periods for each (8).

Category I : Major civil engineering structures - 75 years.
Category II : Buried main and minor civil engineering - 40 years.



Sketch 1. General possible layouts of sprinkler systems.

Category III: Risers and pumps - 20 years.

Category IV: Minor electric switch gear, sprinklers, and mobile pipes - 10 years.

According to Scott (40) a period of 10 to 15 years is often used as a basis for depreciating the sprinkler system as a unit.

Molenaar (34) has assumed depreciation as 8 per cent of the average investment. Houk (17) also points out that depreciation for a sprinkler system is generally assumed as 8 per cent of the average investment.

"The life expectancy of a sprinkler system varies with treatment, use, and storage, but will average about 15 years" (20). Estimated depreciation period for components of an irrigation system determined by Rain-Bird Company are shown in table 6.

Table 6. Estimated depreciation periods for components of an irrigation system (14).

Components	Depreciation years
Well	25
Pump	15
Power units	
Diesel	15
Lp	12
Gasoline, tractor fuel	9
Air cooled gasoline	4
Electric	25
Power mover	10
Concrete pipelines	20
Pipe, steel, coated, underground	20
Pipe, aluminum - sprinkler use	15
Sprinkler heads	8

Taxes and insurance are generally 2 per cent of the average investment (34). Interest rate on irrigation projects is usually figured at 5 per cent of the average value of the system which is half of the purchase price (17 & 30).

Annual fixed costs as studied in the U.S.A. have ranged from $6.50 to $27.10 per acre (40).

3. Annual operation costs. Annual operation costs are influenced by the cost of labor, fuel, water, repair and maintenance of sprinkler system. Labor cost is by far the most important item and varies according to the size of farm, type of crop, layout of sprinkler system, type of system, the time allowed per setting on each farm, and soil conditions (40).

Results of a study made in Utah in 1953 on the relation between labor cost and time of setting were as follows: On three farms where the irrigation schedule called for 4 settings, the labor cost ranged from 0.23 to 0.32 man-hours per acre inch of water application. On other farms using 7, 12, and 24 hour settings, the labor costs were .05, 0.12 and 0.11 man-hours per acre inch of water applied respectively (12).

Extensive labor study in the Sacramento Valley in California covering 37 different systems, resulted in a wide range of labor cost varying from 1.0 to 3.7 man-hours per acre inch of water applied. The average was 1.5 man-hours per acre inch of water application (12).

> Rather meager studies have been reported in Montana, Oregon and Idaho. The Montana results indicate a labor requirement of 0.75 man-hours per acre inch when hay or grain was irrigated, and 1.1 man-hours per acre inch for row crops. The Oregon report simply gives an average of

> 0.59 man-hours per acre inch of water applied, indicating also an average time per setting of 7.5 hours. The Idaho results showed a range of 0.3 to 1.8 man-hours per acre which, if a 3 inch irrigation is assumed, would give a range of 0.1 to 0.6 man-hours per inch (5).

Labor requirements for sprinklers compared with those of surface irrigation in Egypt indicates that the former is $\frac{1}{5}$ of the latter (41).

> Labor costs vary with many factors such as the efficiency of the operator, soil type, topography, height and density of vegetation, pipe size, length and manner of coupling. They also vary with the system design and layout (5).

An average figure for a hand moved system is 1¼ man-hours per acre per irrigation (40).

Estimated labor requirements per acre per irrigation as figured out by Rain-Bird Sprinkler MFG Corporation is given in table 7.

Table 7. Estimated labor per acre per irrigation (14).

Type move	Range minutes	Average minutes	Total time per acre per irrigation minutes or hours
Hand move			
Move	20 - 40	30	
Return	6 - 10	8	38 minutes or 0.63 hours.
Side roll-power			
Move	8 - 12	10	
Return	4 - 6	5	
Straighten	1	1	16 minutes or 0.27 hours.
Tractor end tow			
Move	7 - 11	9	
Return	3 - 5	4	13 minutes or 0.22 hours.

4. Total annual cost. Studies regarding total annual cost in different counties in the United States of American show a wide variation ranging from \$16.50 to \$105.20 per acre (40).

A study carried out in Idaho shows that the total annual cost decreases as the size of irrigation area increases. See table 8.

Table 8. The effect of size of area sprinkled on average annual costs per acre (21).

Component	Size of area sprinkled in acres			
	0 - 24	25 - 49	50 & over	All farms
	No. of farms			
	36	36	33	105
Depreciation	\$8.11	\$5.94	\$5.05	\$5.67
Interest	2.76	2.09	1.65	1.90
Water	2.51	2.34	1.76	2.03
Power	5.21	3.40	2.82	3.17
Repair and maintenance	0.82	0.22	0.21	0.29
Labor	9.22	4.98	4.60	5.27
Total	\$28.63	\$18.97	\$16.09	\$18.23

Annual cost of sprinkler irrigation not only varies with the size of irrigated area, but also with the kind of crop, weather conditions and design factors. Results of several years of study in Washington presented in table 9 are good examples in this respect.

Table 9. Cost of irrigation by sprinklers per acre under varying conditions (36).

Component	Average of		
	1950-54	1956	1957
Pumping power	$5.64	$6.01	$5.08
Interest on investment	3.63	3.95	4.00
Repairs and replacements	1.74	4.60	3.74
Maintenance	0.60	0.36	0.54
Water distribution labor	3.88	6.76	4.10
Total	$ 15.49	$21.68	$17.46

Annual cost of sprinkler irrigation system including electric power consumption, in Egypt, has been found to be L.E. 20.70 per feddan as shown in table 10 (41).

Table 10. Maintenance and operation costs of sprinkler system per feddan in Egypt

Component	Egypt
Electric power consumption	L.E. 13.50
Depreciation and maintenance cost/year	5.25
Annual cost for dismantling and transportation of portable lines and sprinklers	1.95
Total	L.E. 20.70

Annual costs are also influenced by other factors of which the important ones are as follows:

a. Rate of application. The amount of water applied per hour should be as high as the soil can absorb in order to keep the evaporation loss to a minimum. A flow rate higher than that of the soil infiltration capacity leads to run off and lower than that induces extra evaporation loss (46). Therefore the factor that controls the application rate per hour is the texture of soil irrigated. A light soil which is open and pervious allows a higher flow rate to be used by few large laterals and large sprinklers covering a wide area and resulting, possibly, in lower initial investment and lower labor cost in operation of the system. A heavy soil, because of its relatively lower infiltration rate, may require twice as many laterals as a light soil. When the permissible application rate on a heavy soil is one half of that on a light soil, it takes twice as many hours as required to apply a certain amount of water to a light soil. This reduces the number of settings per irrigation and consequently increases the size of the area irrigated per setting per irrigation. Irrigation of a larger area requires more laterals and sprinklers and thus increases the initial cost as well as the annual cost of the sprinkler systems (14).

b. Hours of operation. Hours of operation per day control the number of laterals to be employed which in turn controls the number of sprinklers and the capacity of a sprinkler system required to irrigate a given area in a given time. When the system is to operate only 11 hours a day, there has to be twice as many laterals as used in a system which operates 22 hours a day, that is, 2 settings each 11 hours, in order to be capable to apply the desired depth of water on the same area of land in the given time.

c. Size of sprinkler laterals. In using sprinkler laterals of relatively small diameter there should be a larger pumping unit to overcome the excess friction loss encountered. Savings due to reduced investment in pipe should be carefully analyzed in terms of additional investment and operating cost of increased power requirement, in order to attain a reasonable balance between equipment costs and power costs (46). To maintain uniform distribution throughout a sprinkler line, the size of lateral has to be chosen in a way to have a friction loss not more than 20 per cent of operational head at the beginning of the line (40).

d. Layout of laterals. It is recommended to place laterals across the wind. Under this arrangement, the distance between laterals is increased and thus the number of laterals required for a given area is decreased, making it possible to lower the initial cost (34).

e. Irrigation frequency. "Most or practically all of the evaporation losses take place from the wetted surface while irrigating, and from the upper 2" to 4" of soil, depending on soil texture, during the first 3 or 4 days after irrigation" (14). Thus, light and frequent irrigation results in larger quantity of water loss through evaporation (14), and higher labor cost (40).

f. Type of system. Water application by different systems results in different costs. Russia has put great emphasis on designing a sprinkler system that will apply water at the lowest annual cost. During the recent years about 40 different designs of sprinkling and watering machines have been developed and research is still going on for development of better ones (10).

DESIGN SPECIFICATIONS AND COST DATA

A. Physical Basis for System Design.

A specific sprinkler system is generally designed for each specific farm. The aim of this study is to determine the cost of irrigation by sprinklers and the effect of wind on this cost for the whole Bekaa area. One approach to this problem would be to take as many specific sprinkler systems as possible and evaluate them and then draw a general conclusion. The other would be to make one design, based on synthesized conditions representing the area in general and then evaluate that one alone. The latter approach was followed in this study.

The basic factors on which proper design of a farm irrigation sprinkler system should be based are the following:

1. Topographic details of the land to be irrigated.

2. The soil characteristics - mainly water intake rate, and available water holding capacity of the root zone.

3. The water supply; its source, quality and quantity, delivery schedule, and seasonal variation.

4. The crop to be irrigated; its effective root depth, peak consumptive use, and total water use.

5. The expected irrigation efficiency in applying water to the land which is determined by three factors.

a. Rate of application within the limit of the soil infiltration capacity.

b. High uniformity of water distribution.

c. High minimum depth of water at any location within the area irrigated.

6. The irrigation frequency which is determined by the rate of evapotranspiration of the crop and the quantity of water applied in the last irrigation. It is also influenced by the soil moisture holding characteristics and the level of available moisture desired to be maintained in the soil.

7. The climatic data -- mainly effective precipitation, intensity of rain fall, and direction and duration of prevailing winds.

For the purpose of designing a sprinkler system for general use in the Bekaa, according to the above basic design factors, certain assumptions were made and available data related to the Bekaa were utilized.

1. The land is assumed to be rectangular — twice as long as wide, and relatively flat.

2. The soil is assumed to be 1 meter deep with medium texture having an infiltration rate of 0.5" or 12.7 mm per hour (14). Meager study concerning infiltration rate of different plots at AREC has given an average figure of about 12.9 mm per hour (table 11) which is close to that of medium textured soil given in the above reference. Available water holding capacity of such a soil to a depth of 1 meter is 140 mm (14).

3. The water is assumed to be available from a stream passing continuously along one end of the field in a sufficient quantity and of

proper quality throughout the growing period of the crop.

Table 11. Infiltration rate of different plots at AREC in mm/hour (29).

Plot	Crop grown	Test number and infiltration rate in mm/hour				Average in mm/hour
		1	2	3	4	
B14c	Sugar beet	3.8	11.0	13.0	4.4	8.05
B15a	Sugar beet	8.1	12.7	8.7		9.8
B15d	Potato	12.3	51.2	5.8		23.1
B15e	Potato	7.6				7.6
B64a	Potato	4.3	2.4	8.3	23.0	9.5
B63	Bean	18.0	11.1	44.0	41.0	19.3
			Overall average			12.9 mm/hr.

4. The crop chosen in this study is sugar beet. The reasons for its selection are: (1) rapid growth of area allocated for sugar beet production in the Bekaa plain, and (2) the root depth of sugar beet as 3 feet or 1 meter which lies between deep rooted plants like apples with 5 to 6 feet root depth and shallow rooted vegetables such as lettuce and onion with 1 foot of feeder root depth (7). Due to the lack of actual peak consumptive use figures for sugar beets in the Bekaa, the peak use was determined as follows: The consumptive use of the crop, for a period covering 2 peaks, as determined by a 1 year experiment at AREC, was averaged. The value thus obtained-8.68 mm per day - is used here as a representative peak consumptive use of sugar beet in the

Bekaa (28). The reason for this procedure is the fact that the consumptive use obtained from the 1 year experiment has not been confirmed by data for other years. Also it is considerably higher than that reported by the California Agricultural Experiment Station for the Sacramento - San Jaquin Valley where climatic conditions are fairly similar to those in the Bekaa area. Their finding for sugar beet has been 0.61 feet per month which is 6 mm per day (16).

The water use of early sugar beet as determined at AREC from June to October 1962 was 981.24 mm (28). This water use covers the main part of the growing season of the crop but not the whole season. Sugar beet yields are maximum when the crop is planted at March 15 and harvested at November 15. To obtain water use for the whole season, from March to November, the 981.24 mm reported for June to October was arbitrarily increased by 50 per cent. Thus the total water use by the crop is calculated to be 1431.86 mm for the season.

5. Irrigation efficiency. Use is made of the work reported on by Mutayreh relative to uniformity of distribution and spacings, using rectangular pattern with a fixed pressure and nozzle size. Using 40 pound per square inch of pressure with 3/16" x 3/32" - 7^{0} nozzle, he has come to the conclusion that a layout of 12 x 12 m under low wind conditions gives a uniformity coefficient of 93.9 per cent with the least application rate being 7.42 mm per hour, and under high wind conditions provides a uniformity coefficient of 80 per cent with 3.99 mm as the least application rate per hour (35). Table 12 shows the detailed distribution pattern under both low and high wind conditions.

Table 12. Depth of water contributed by sprinklers with a square layout of 12 x 12 m. under low and high wind conditions in mm/hour (35).

Low wind				High wind			
Grid*		Grid		Grid		Grid	
A_1	8.73	D_1	8.50	A_1	9.71	D_1	10.91
A_2	8.74	D_2	7.54	A_2	10.10	D_2	8.52
A_3	8.04	D_3	7.85	A_3	10.01	D_3	3.99
A_4	7.69	D_4	7.91	A_4	7.67	D_4	4.67
A_5	9.03	D_5	8.54	A_5	7.61	D_5	6.61
A_6	9.65	D_6	8.65	A_6	8.73	D_6	9.62
B_1	8.22	E_1	9.55	B_1	9.60	E_1	10.08
B_2	8.61	E_2	8.90	B_2	9.98	E_2	8.30
B_3	7.84	E_3	7.97	B_3	8.13	E_3	5.44
B_4	8.69	E_4	8.04	B_4	6.82	E_4	5.26
B_5	8.99	E_5	9.52	B_5	5.96	E_5	8.12
B_6	9.18	E_6	9.38	B_6	7.54	E_6	11.53
C_1	7.92	F_1	9.66	C_1	8.82	F_1	9.06
C_2	7.42	F_2	8.78	C_2	7.72	F_2	9.24
C_3	8.36	F_3	7.72	C_3	6.10	F_3	7.88
C_4	8.45	F_4	7.81	C_4	4.82	F_4	7.74
C_5	8.91	F_5	8.74	C_5	5.21	F_5	8.81
C_6	8.90	F_6	9.23	C_6	6.54	F_6	10.60

*Grid origin: North-west corner,
and A,B,C .... F indicate North-south direction from origin
and 1,2,3 .... 6 indicate West-east direction from origin.

Mutayreh has also found that a layout of 8 x 10 m under high wind conditions provides a uniformity coefficient of 92.6 per cent. The application rates being much higher than the soil intake capacity, as is seen in table 13, rule out its use.

Table 13. Depth of water contributed by sprinklers with a rectangular layout of 8 x 10 m under high wind conditions in mm/hour (35).

Grid		Grid	
A_1	15.22	C_3	12.05
A_2	16.07	C_4	13.74
A_3	16.07	D_1	13.99
A_4	15.12	D_2	12.82
B_1	14.40	D_3	12.44
B_2	14.14	D_4	14.82
B_3	13.34	E_1	14.69
B_4	13.81	E_2	15.52
C_1	13.44	E_3	15.54
C_2	12.95	E_4	16.41

Because of the recommendation of McCulloch (31) and Bauzil (7) to use triangular pattern in windy areas to overcome the adverse effect of wind on sprinklers, it was necessary to know what uniformity coefficients triangular patterns would provide. To have comparable results, the same typical values that Mutayrah had obtained were used in the study. See figure 2. Several layouts were evaluated. For each layout

N

				0.22	0.34	0.31	0.36	0.36	0.25	0.20		
			0.25	0.36	0.58	0.63	0.60	0.58	0.43	0.40	0.20	
		0.25	0.58	0.78	1.30	1.26	1.21	1.17	1.08	0.72	0.40	0.16
	0.25	0.63	1.55	1.79	2.06	2.15	2.11	1.77	1.68	1.26	0.67	0.31
0.18	0.54	1.66	2.04	2.35	2.60	2.58	2.60	2.06	1.88	1.79	1.30	0.63
0.40	1.17	2.04	2.51	3.25	3.99	3.95	3.34	2.33	2.06	1.93	1.73	1.12
0.94	1.82	2.24	3.21	4.73	5.38	5.27	4.57	2.94	2.38	2.02	1.93	1.19
1.08	1.97	2.46	3.61	4.91	5.47	5.58	5.13	3.38	2.40	2.13	1.90	1.16
W					X							E
1.03	1.97	2.55	3.52	4.86	5.47	5.65	5.20	3.76	2.51	2.11	1.90	0.96
0.81	1.75	2.17	3.02	4.01	4.70	4.95	4.50	3.27	2.44	1.93	1.75	0.36
0.63	1.03	1.82	2.38	2.89	3.68	3.90	3.25	2.82	2.15	1.88	1.32	
0.36	0.70	1.26	1.55	1.97	2.44	2.67	2.33	2.22	1.79	1.39	0.49	
	0.36	0.70	1.10	1.43	1.73	1.84	1.74	1.73	1.10	0.92		
		0.43	0.63	0.94	1.08	1.21	1.08	0.87	0.49			
				0.56	0.58	0.63	0.36	0.31				

S

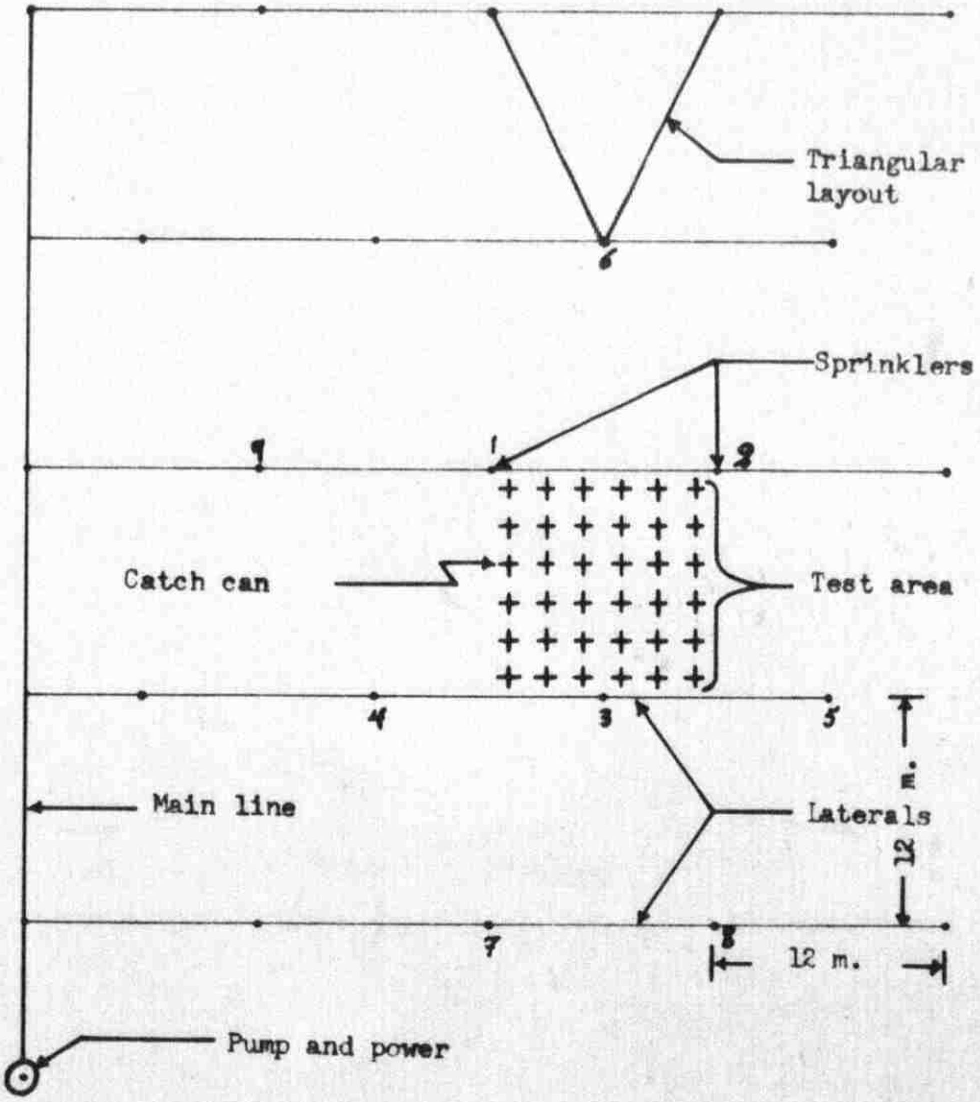
Figure 2. Water distribution pattern - average of the 4 low wind tests, 1, 2, 3, and 4.

Figures shown are depth of application in millimeters per hour (35).

X represents sprinkler in the test area. Direction of wind is southwest.

a sketch similar to sketch No. 2 was prepared. The numbers in sketch 2 refer to the sprinklers that could contribute water to the test area. The total contribution to the test area is shown in figure 3, where the individual sprinkler contributions are recorded opposite each sprinkler number. The total contribution at each grid is used for determining the uniformity coefficient by Christiansen formula, $Cu = 100 \left(1 - \frac{\Sigma y}{mn}\right)$ as shown in table 14.

The same procedure was followed for determination of the optimum triangular layout on the basis of uniformity coefficient, under high wind conditions. Table 15 shows a comparison of the layouts analysed for both low and high wind conditions.



Sketch 2. Plan of a 12 x 12 m. triangular layout.

5.65(1)	- (5)	5.20	-	3.76	-	2.51	-	2.11	-	1.90	0.25
1.03(2)	- (6)	1.97	0.56	2.55	0.58	3.52	0.63	4.86	0.36	5.47	0.31
0.58(3)	- (7)	0.78	-	1.30	-	1.26	-	1.21	-	1.17	-
1.08(4)	- (8)	0.78	-	0.40	-	0.26	-	-	-	-	-
	0.96(9)										
	9.30		9.23		8.59		8.08		8.54		9.10
4.95	-	4.50	-	3.27	-	2.44	-	1.93	-	1.75	0.63
0.81	-	1.75	-	2.17	-	3.02	-	4.01	-	4.70	-
1.55	-	1.79	-	2.06	-	2.15	-	2.11	-	1.77	-
1.68	-	1.26	-	0.67	-	0.31	-	-	-	-	-
	0.36										
	9.29		9.30		8.17		7.92		8.30		8.85
3.90	-	3.25	-	2.82	-	2.15	0.18	1.88	0.54	1.32	1.66
0.63	-	1.03	-	1.82	-	2.38	-	2.89	-	3.68	-
2.04	-	2.35	-	2.60	-	2.58	-	2.60	-	2.06	-
1.88	-	1.79	-	1.30	-	0.63	-	-	-	-	-
	8.45		8.45		8.54		7.92		7.91		8.72
2.67	-	2.33	-	2.22	-	1.79	0.40	1.39	1.17	0.49	2.04
0.36	-	0.70	-	1.26	-	1.55	-	1.97	-	2.44	-
2.51	-	3.25	-	3.99	-	3.95	-	3.34	-	2.33	-
2.06	-	1.93	-	1.73	-	1.12	-	-	-	-	-
	7.60		8.21		9.20		8.81		7.87		7.30
1.84	-	1.79	-	1.73	-	1.10	0.94	0.92	1.82	-	2.24
-	-	0.36	-	0.70	-	1.10	-	1.43	-	1.73	-
3.21	0.31	4.73	0.36	5.38	0.36	5.27	0.25	4.57	0.20	2.94	-
2.38	-	2.02	-	1.93	-	1.19	-	-	0.22	-	0.34
	7.74		9.26		10.10		9.85		9.16		7.25
1.21	-	1.08	-	0.87	-	0.49	1.08	-	1.97	-	2.48
-	-	-	-	0.43	-	0.63	-	0.94	-	1.08	-
3.61	0.63	4.91	0.60	5.47	0.58	5.58	0.43	5.13	0.40	3.38	0.20
2.40	-	2.13	-	1.90	-	1.16	0.25	-	0.36	-	0.58
	7.85		8.72		9.25		9.62		8.80		7.70

Figure 3. Chart showing depth of water contributed by sprinklers in mm/hr. in order of their numbers as shown by sketch 2. The values are obtained from figure 2. Spacing 12 x 12 m - pattern triangular - low wind.

Table 14. Calculation of C.U.* for the 12 x 12 m triangular layout under low wind conditions.

N	Values observed in mm.	y
1	9.30	0.72
2	9.29	0.71
3	8.45	0.13
4	7.60	0.98
5	7.74	0.84
6	7.85	0.73
7	9.23	0.65
8	9.30	0.72
9	8.42	0.16
10	8.21	0.37
11	9.26	0.68
12	8.72	0.14
13	8.59	0.01
14	8.17	0.41
15	8.54	0.04
16	9.20	0.62
17	10.10	1.52
18	9.25	0.67
19	8.08	0.50
20	7.92	0.66
21	7.92	0.66
22	8.81	0.23
23	9.85	1.27
24	9.62	1.04
25	8.54	0.04
26	8.30	0.28
27	7.91	0.67
28	7.87	0.71
29	9.16	0.58
30	8.80	0.22
31	9.10	0.52
32	8.85	0.27
33	8.72	0.14
34	7.30	1.28
35	7.25	1.33
36	7.70	0.88

mn = 308.92 $\Sigma y = 21.38$

m = 308.92/36

= 8.58

$$CU = 100(1 - \frac{21.38}{308.92})$$

$$= 100 - 6.9$$

$$= 93.1\%$$

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* Coefficient of uniformity.

Table 15. Comparison of the uniformity coefficients of different triangular layouts under low and high wind conditions.

Spacings tested in meters		Uniformity coefficent %	
Between sprinklers	Between laterals	Low wind	High wind
14	14	92.50	-
12	14	92.58	76.90
12	12	93.10	80.72
10	12	92.95	85.72
10	10	-	89.53
8	10	-	92.38
8	8	-	95.94
6	8	-	97.80
6	6	-	94.55

The one with the highest uniformity coefficient and with an application rate not exceeding the infiltration rate of the soil is considered the most desirable.

The 6 x 8 m. layout under high wind conditions provides 97.80 per cent uniformity coefficient, but is ruled out because of its high application rate. See table 16. The infiltration capacity of soil is 12.7 mm. per hour. Application rate higher than 12.7 mm. per hour results in run off.

Table 16. Depth of water contributed by sprinklers in mm/hour in the 6 x 8 m triangular layout under high wind conditions.

Grid		Grid	
A_1	22.88	C_1	22.23
A_2	24.37	C_2	23.68
A_3	23.34	C_3	24.07
B_1	23.58	D_1	24.91
B_2	23.64	D_2	23.13
B_3	24.22	D_3	23.43

The 12 x 12 m. layout with isosceles triangular pattern gives 93.1 per cent uniformity coefficient under low wind and 80.72 per cent under high wind conditions. See table 17.

Table 17. Depth of water contributed by sprinklers with the 12 x 12 m. triangular layout under low and high wind conditions in mm/hour.

Low wind				High wind			
Grid		Grid		Grid		Grid	
A_1	9.30	D1	8.08	A_1	9.05	D_1	9.33
A_2	9.29	D_2	7.92	A_2	7.40	D_2	9.02
A_3	8.45	D_3	7.92	A_3	4.97	D_3	7.67
A_4	7.60	D_4	8.81	A_4	4.71	D_4	10.87
A_5	7.74	D_5	9.85	A_5	5.15	D_5	10.14
A_6	7.85	D_6	9.62	A_6	6.95	D_6	9.85
B_1	9.23	E_1	8.54	B_1	9.92	E_1	7.74
B_2	9.30	E_2	8.30	B_2	8.10	E_2	7.84
B_3	8.42	E_3	7.91	B_3	6.35	E_3	6.58
B_4	8.21	E_4	7.87	B_4	6.53	E_4	8.60
B_5	9.26	E_5	9.16	B_5	8.26	E_5	8.16
B_6	8.72	E_6	8.80	B_6	8.78	E_6	9.27
C_1	8.59	F_1	9.10	C_1	10.62	F_1	8.12
C_2	8.17	F_2	8.85	C_2	9.31	F_2	6.36
C_3	8.54	F_3	8.72	C_3	8.00	F_3	4.64
C_4	9.20	F_4	7.30	C_4	9.62	F_4	3.99
C_5	10.10	F_5	7.25	C_5	11.53	F_5	5.44
C_6	9.25	F_6	7.70	C_6	11.14	F_6	7.34

The application rate in both cases is lower than the infiltration rate of soil and thus is permissible.

Comparison of the results obtained from the triangular layout with those from the rectangular one indicate that both patterns, operating under similar conditions, are similar in overcoming the detrimental effect of wind. In other words, it is spacing rather than pattern that levels out the irregularity in distribution of water and results in higher uniformity coefficient. Hence the recommendations of McCulloch (31) and Bauzil (7) to use triangular pattern in windy areas to overcome the adverse effect of high wind on sprinklers do not prove fruitful under conditions in this experiment. Triangular pattern may prove to be more effective than rectangular one in offsetting the effect of high wind and applying water uniformaly when used with low pressure and wide spacings, as mentioned by Selim and Nichola (41), but this falls beyond the scope of this work.

Therefore, the efficiency of a 12 x 12 m rectangular layout under both low and high wind conditions proves to be the most desirable one for consideration in design and economic analysis.

6. Irrigation frequency. Rather than assigning a fixed frequency, it seems desirable to establish a time setting for the sprinkler system which when coupled with a given rate of water use will yield a given frequency. According to Shafique (42) sugar beets are relatively insensitive to moisture stress and yield becomes affected only when the irrigation interval exceeds 10 days. Operating the sprinkler system 9 to 11 hours per setting provides an irrigation interval of 7.5 to 9 days

respectively. This allows the field to maintain a level of available moisture from 56.4 to 50 per cent. The recommended level to start irrigation is when the soil moisture is depleted about 45 per cent (39).

7. Climatic data.

a. Effective precipitation. This is a function of several factors which are interrelated. Mainly it is influenced by rainfall during growing season, rainfall before planting the crops,intensity and duration of rain, rate of water use by crop, root depth of crop, soil infiltration capacity and its moisture content before precipitation. Due to these interrelated factors which complicate the measurement of effective precipitation, rainfall less than one fourth of an inch in any one day is disregarded (44), and arbitrarily one third of the precipitation occuring during the plant growing season is considered as the effective precipitation. Of the rainfall occuring during winter, only the amount required to satisfy the soil moisture capacity at the rootzone is taken as part of the effective precipitation. Thus the total effective precipitation, according to the weather data at AREC (3), during the growing season of sugar beet from March 15 to November 15, will be as follows:

April 1962 .... = 12.43 mm
October 1962 .... = 2.97 mm
Precipitation stored in the upper 1 m of soil in winter .... = 140.00 mm

Total eff. ppt. = 155.40 mm

The safe seasonal water requirement will therefore be 1431.86 - 155.40 = 1276.46 mm.

b. Wind. Due to rise of surface heat shortly after midday, atmospheric stability decreases, frictional forces become reduced to a minimum, and thus the surface wind speed reaches a maximum. The reverse is true with decrease of surface temperature (26). Based on this phenomenon, and what is actually observed in the Bekaa plain, it is assumed that wind with velocities high enough to distort the distribution pattern of water discharged from sprinklers lasts about 5 hours, namely, from 1 p.m. to 6 p.m. Statistical analysis is required to determine the probability of occurence of high wind and its duration at any time.

c. Direction of prevailing wind as determined by AREC weather station is south-west (35). This necessitates laterals to be placed in SE - NW direction, in order to decrease the number of laterals required for a given area and to lower the initial cost of sprinkler system.

B. Cost data.

The cost of irrigation by sprinklers is composed of both fixed and variable expenses. The following cost data are assumed in the economic analysis of the same systems designed later in this study.

1. Equipment and supplies. Tables 18, 19, and 20 show the 1964 prices of the various items of equipment used for sprinkler systems. These are obtained from two firms in Beirut and represent prices farmers would have to pay.

Fuel is counted @ LL. 118.20 per 1000 liters, the prevalent price in the market.

Lubricating oil and engine maintenance is taken at 40 per cent of the fuel charge (34).

Repair of pipelines and fittings is figured at 3 per cent of their original cost (34).

Interest on investment is figured at 5 per cent of the average investment, equal to the return that would be obtained if capital were invested elsewhere or put in bank. **Average investment = $\frac{1}{2}$/of initial cost.**

Annual depreciation rate for each item of the system is figured separately on the basis of their useful life estimated by Rain-Bird Sprinkler MFG Corporation as shown in table 6.

Tax and insurance are taken at 2 per cent of the average investment as recommended by many workers (34).

Table 18. Price list of galvanized steel products in LL.

Items	Diameter in mm					
	50	70	89	108	133	159
Pipe in standard 6 m length*	41.80	52.00	70.60	92.60	134.50	182.40
Pipe in 3 m sublength	23.00	27.50	39.00	50.00	73.00	100.00
Reducer	20.00	27.00	38.50	53.00	67.00	-
Side outlet tee without valve	31.00	34.50	41.50	47.00	54.00	100.00
Side outlet tee with valve	62.00	83.00	90.00	97.50	109.00	207.00
Sprinkler connecting clamp	5.00	5.00	5.00	-	-	-
Pipe support leg	4.50	6.75	7.00	7.50	10.50	-
End plug	12.00	16.50	22.00	28.00	36.50	48.00
Discharge pump connection	23.25	28.52	39.37	49.60	61.07	80.00
Delivery connection curve	58.00	71.00	91.00	127.00	173.00	242.00
90 degree bend	22.00	27.00	36.00	50.00	68.00	113.00
Strainer	-	80.00	93.00	110.00	125.00	150.00

*This includes male and female parts.

Table 19. Price list of aluminum products in LL.*

Item	Diameter in inches				
	2	3	4	5	6
Main line pipe 20 ft. long	35.65	50.22	68.20	88.66	116.25
Lateral pipe, 20 ft., with riser outlet	37.20	51.77	69.75	90.83	118.42
Reducer	-	23.56	32.55	41.85	46.81
Side outlet tee without valve	-	43.40	51.15	69.75	91.45
Riser	0.77	1.55	1.55	1.55	1.55
End plug	10.85	13.33	17.05	21.70	26.35
90 degree bend	24.80	32.55	44.95	57.35	75.95
Discharge pump connection	23.25	28.52	39.37	49.60	61.07
Cross	46.50	58.90	74.40	100.75	124.00

Pressure gauge with 100 lb. dial = LL. 6.82.

Sprinkler 3/16" x 3/32" - 7° = LL. 13.95.

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* These are FOB prices and should be increased by 35 percent to include CIF and custom clearances.

Table 20. Price list of pumps and diesel engines in LL.

Item	Capacity	Head in feet	RPM	H.p.	Unit price in LL.
Centrifugal pump	60	120	1450		410
	100	120	1450		410
	200	125	1450		500
	300	130	1800		720
	400	135	1850		720
	500	140	1750		920
Diesel engine			1500	5	1680
			1500	8.5	2270
			1500	12.5	2500
			1800	20	3540
			1800	30	4910
			1800	40	5940
			2000	78	11280

2. Labor requirements and costs. Labor requirement for moving sprinkler laterals was determined through observation of actual operation of sprinkler systems in four different farms in Lebanon. Due to the limitation of sprinkler units to four farms in the whole country, at the time of study in 1964, it was not possible to maintain constancy in conditions, namely, the shape of irrigated area, the type of crop grown, the irrigation interval, the size of pipe and spacing which affect directly or indirectly the time required to move laterals per irrigation.

Out of the four farms visited, two were orchards, A and B, one a recently established experimental farm, and the fourth an already established crop plots on AREC. In the orchards, the laborers had liberty to walk in any direction that seemed convenient and facilitated movement of laterals. In the experimental farm, laborers had to follow certain paths marked at 12 meter intervals along the lateral lines in order not to tramp on the plants. At AREC with the well developed plants, laborers tended not to break the plants while crossing the rows, and sometimes avoided crossing the rows by walking along the border and entering the rows only at areas where the laterals had to be placed.

Man-hours required for handling of sprinkler laterals was partly influenced by these factors, but the main factor causing wide range in labor requirements among the different farms was the management problem. In orchard "A" (table 22), each laborer was individually responsible only for moving 2 laterals twice a day. Under this arrangement they did their job more efficiently than those who worked as a group and whose responsibility was to work all day long on different tasks.

In the four farms visited, lateral movement was accomplished manually without any mechanical device to tow or carry pipes from one position to another. On the AREC plots, a tractor was used to transport the pipes from one plot to another and save the time and energy that would have been required from the laborers.

Owing to these variations, an attempt was made to average the time spent by different laborers in moving laterals by considering the wage paid them.

This may not be the exact labor cost for any specific farm, but can be adequate for design and economic analysis of sprinkler system in the area.

Wage rate and work hours per day in four different farms visited are shown in table 21.

Table 21. Man-hour wage rates in LL. in Lebanon

	Farm			
	Orchard A	Orchard B	Experimental farm	AREC farm
Wage rate per day	4	5	5	3
Work hours per day	2	10	8	8
Actual wage per hour	2	0.5	0.625	0.375

Tables 22, 23, 24 and 25 show the actual time spent at each farm in moving laterals.

Table 22. Time of handling of laterals per irrigation in Orchard "A", June 1964.

Spacing in meters	Lateral		Area irrigated in meter^2	Number of laborers involved	Time to remove lateral line and reinstall in the next position
	Length in meters	No.			
12 x 12	84 + 6*	1	96 x 12 = 1152	1	13 min.
"	168 + 9	1	180 x 12 = 2160	1	18 min.
"	108 + 6	1	120 x 12 = 1440	1	15 min.
"	72 + 9	1	84 x 12 = 1008	1	13 min.
"	36 + 9	1	48 x 12 = 576	1	7 min.
"	168 + 9	1	180 x 12 = 2160	1	18 min.
"	120 + 6	1	132 x 12 = 1584	1	15 min.
"	60 + 6	1	72 x 12 = 864	1	8.5 min.
Total			Area = 10944 m^2		Time = 107.5 min.

*This indicates the distance between main and first sprinkler. Where main was located on opposite side of the road, this distance was 9 m.

In addition to the time spent in moving laterals in each plot, it took 2 minutes extra for laborer to walk from one plot to the other. Taking this into account and considering Orchard A, the total time spent for moving the laterals to irrigate 1.094 hectare of land becomes 107.5 + 2 x 8 = 123.5 minutes, or $\frac{123.5}{1.094 \times 60}$ = 1.9 man-hoursper hectare per irrigation, and labor cost becomes 1.9 x 2 = LL 3.8 per hectare per irrigation.

Table 23. Time of handling of laterals per irrigation in Orchard "B". July 1964

Spacing in meters	Lateral		Area irrigated in meter^2	Number of laborers involved	Time to remove lateral line and re-install in the next position
	Length in meters	No.			
12 x 12	66	3	72 x 36 = 2592	4	19 min.
"	66	4	72 x 48 = 3456	4	30 min.
"	54	3	60 x 36 = 2160	4	24 min.
	Total		Area = 8208 m^2		Time = 73 min.

Considering Orchard B the total time spent was 73 + 2 x 3 = 79 minutes.

Applying the above data to 1 hectare of cultivated surface per man, it gives $\frac{79 \times 4 \times 10000}{8208}$ = 384 minutes or 6.4 man-hour per hectare per irrigation, and labor cost becomes 6.4 x 0.5 = LL 3.2 per hectare per irrigation.

Table 24. Time of handling of laterals per irrigation in experimental farm. June 1964

Spacing in meters	Lateral: Length in meters	No.	Area irrigated in meter^2	Number of laborers involved	Time to remove lateral line and reinstall in the next position
12 x 12	96	3	108 x 36 = 3888	2	56 min.
"	96	3	108 x 36 = 3888	3	36 min.
"	96	3	108 x 36 = 3888	3	49 min.
	Total		Area = 11664m^2		Time =141 min.

Considering the experimental farm and converting the data in table 24 to 1 hectare of cultivated surface per man it gives

$$\frac{(56 \times 2 + 36 \times 3 + 49 \times 3)10000}{11664} = 314 \text{ min.}$$

or 5.2 man-hours per hectare per irrigation, and labor cost becomes 5.2 x 0.625 = LL 3.25 per hectare per irrigation.

Table 25. Time of handling of laterals per irrigation in AREC farm in Bekaa. June 1964.

Spacing in meters	Laterals: Length in meters	No.	Area irrigated in meter^2	Number of laborers involved	Time to decouple lateral pipes & load on tractor	Time to transport pipes by tractor to other field	Time to install lateral pipes on new position
6 x 12	84	1	84x12=1008	5	6 min.	4 min.	25 min.
"	66	1	66x12=792				
"	30	1	30x12=360				
6 x 12	84	1	84x12=1008	5	10 min.	7 min.	20 min.
"	48	1	48x12= 576				
"	48	1	48x12= 576				
	Total		4320m^2				

Considering the AREC plots and excluding the time spent on transportation of pipes by tractor, the total time spent on decoupling and reinstalling the laterals by one man becomes $5 \times (6 + 25 + 10 + 20) = 305$ min.

Applying the fore-said data to 1 hectare cultivated surface per man it gives $\frac{305 \times 10000}{4320} = 706$ minutes or $706 \div 60 = 11.7$ man-hours per hectare per irrigation, and labor cost becomes $11.7 \times 0.375 =$ LL. 4.38 per hectare per irrigation.

Therefore the range for labor cost is from 3.2 to 4.38 LL. per hectare per irrigation and the average is $\frac{3.8 + 3.2 + 3.25 + 4.38}{4} =$ LL. 3.66 per hectare per irrigation.

Charge for mechanic or technician hired to operate pump and engine at LL. 300 per month with 10 hours of work per day gives a cost as $\frac{300}{30 \times 10} =$ LL. 1 per hour.

3. Water charges. There is no announced monetary value for water in the Bekaa area. Farmers who rent irrigated land for crop production get the right to use water with the use of the land.

For comparing alternatives it is essential to give a value for water. The cost of water may be estimated in several methods. Two methods are detailed here. One assumes water is available in liberal quantities at shallow depths not exceeding 3 meters and its cost is the cost of pumping it to the surface under pressure. The other assumes that water is in limited supply and its cost can be calculated by subtracting the average rent of land suitable for sugar beet production in the central Bekaa excluding irrigation water from the average land including irrigation water (32).

Water cost under the first assumption.

Consumptive use of sugar beet per season = 1431.86 mm.

Effective precipitation = 155.40 mm.

Application efficiency (37) = 62.50 %

Irrigation requirement = $\frac{1431.86-155.40}{62.50} \times 100$ = 2042.3 mm.

Capacity of pump to be installed (p.57) = 171.40 gpm.

Delivery head (p.61) = 125 ft.

Diesel power required = 9.6 hp.

Cost of application of water through pump under pressure.

Initial costs:

Centrifugal pump @ LL.500 = LL. 500.00

Diesel engine @ LL. 2500 = 2500.00

Suction pipe @ LL. 27.50/3 m. = 27.50

90 degree bend @ LL. 27.00 = 27.00

Strainer @ LL. 80.00 = 80.00

Total = LL.3134.50

Annual fixed costs:

Centrifugal pump and diesel engine = LL. 288.90

(Initial cost LL.3000, life 15 years and
capital recovery factor 0.0963)

Suction pipe, bend and strainer = LL. 10.79

(Initial cost LL. 134.50, life 20 years, and CRF 0.0802)

Tax and insurance @ 2 per cent of average investment =LL.31.34

Total = LL. 331.03

Annual variable costs:

Volume of water to be applied per season to a 5 hectare farm

$$\frac{2042.3 \times 50000}{1000} = 102115 \text{ m}^3$$

Volume of water pumped per hour

$$\frac{171.40 \times 60 \times 3.7853}{1000} = 38.928 \text{ m}^3$$

Hours engine operated per year

$$102115 \div 38.928 = 2623 \text{ hours}$$

BHP - Hours per year

$$2623 \times 9.6 = 25180.8 \text{ BHP - Hrs.}$$

Amount of diesel fuel @ 1 gallon per 11.2 BHP - Hrs. (14)

$$25180.8 \div 11.2 = 2248.28 \text{ gallons}$$

Fuel cost @ LL. 118.20 per 1000 liters

$$\frac{2248.28 \times 3.7853 \times 118.20}{1000} = \text{LL. } 1006.00$$

Lubricant and engine maintenance @ 40 per cent of above

$$1006 \times \frac{40}{100} = \text{LL. } 402.40$$

Attendance for pump and engine @ 1 hour per day

$$180 \times 1 = \text{LL. } 180.00$$

Total variable costs per year = LL. 1588.40

Total annual costs = 1588.40 + 331.03 = LL. 1919.43

Water cost = 1919.43 ÷ 102115 = 1.9 piasters per m^3.

Water cost under the second assumption.

According to a study of sugar beet production in the Bekaa area carried out by the Institute of Rural Economics, the average rent for land supplied with irrigation water pumped from deep wells was LL.76 per dunum, while the rent of similar land but with the cost of irrigation water borne by the tenant was LL. 33 per dunum. Hence, the cost of irrigation water for sugar beet production in the Bekaa averaged LL. 43 per dunum (32). This included the cost of pumping water from deep wells to the land surface plus the value of water itself. The cost of water itself can be figured by subtracting the cost of pumping from the cost of water pumped to the surface of the land. The cost of pumping water can be calculated as follows:

Assuming the depth of well to be 80 feet, the diesel power required will be $\frac{171.40 \text{ gpm (p.57)} \times 80 \times 100}{3960 \times 70} \times 1.25 = 6.2$ hp.

Initial cost:

Diesel engine	LL. 2270
Deep well turbine pump with shaft, column & impellers	LL.3000
Total initial cost	LL. 5270

Annual fixed costs .... LL. 507.50

(Life 15 years and CRF 0.0963)

Annual variable costs:

BHP - Hours per year

2623 hours (p.52) x 6.2 = 16262.6 BHP - Hrs.

Amount of diesel fuel @ 1 gallon per 11.2 BHP -Hrs. (14)

16262.6 ÷ 11.2 = 1452.02 gallons.

Fuel cost @ LL. 118.20 per 1000 liters

$\frac{1452.02 \times 3.7853 \times 118.20}{1000}$ = LL. 649.67

Lubricant and engine maintenance

$649.67 \times \frac{40}{100}$ = LL. 259.87

Attendance for pump and engine @ 1 hour per day

180 x 1 = LL. 180.00

Total variable costs per year = LL. 1089.50

Total annual cost = 1089.50 + 507.50 = LL. 1597.00

Cost of pumping water from deep well to the land surface

1597 ÷ 102115 (p.52) = 1.6 piasters per m^3.

Volume of water to be applied to an area of 1 dunum

2.0423 m x 1000 m^2 = 2042.30 m^3 per dunum.

Cost of pumping water from deep well to a 1 dunum area

2042.3 x 1.6 = LL. 32.67 per dunum.

Value of water itself $\frac{43 - 32.67}{2042.30}$ = 0.5 piasters per m^3.

SYSTEM DESIGN AND COST ANALYSIS

The purpose of this chapter is to design a typical sprinkler irrigation system corresponding to the general design specifications established so far. The cost of such a system is determined and then the effect of kind of equipment, type of system and size of area to be irrigated are evaluated. Finally, the effect of wind is determined by comparing the cost of sprinkling under no or low wind conditions with actual costs of sprinkling under the conditions actually existing or assumed in the Bekaa.

A. Design of a Typical System.

Before going into the details of the design of this system which is assumed to operate under no or low wind conditions, it would seem advisable to summarize the various design specifications established in the previous chapter. Using outline form these are the following:

Land:

Shape	Rectangular, length 2 x width
Slope	Negligible

Soil:

Texture	Medium
Maximum infiltration rate	12.7 mm/hr.
Depth	1 m.
Available water holding capacity	140 mm/m.

Water:

Source	Stream flow 3 ms. deep.
Location	At one end of the field.
Supply	Continuous
Quality	Good
Amount	Proportional to area.

Crop:

Kind	Sugar-beet
Feeder root depth	1 m.
Peak consumption use	8.68 mm/day
Total water use	1431.86 mm/season.

Irrigation efficiency:

Sprinkler size	3/16" x 3/32" - 7°
Pressure	40 lb./in^2
Spacing	12 x 12 m. square.
Discharge rate	578 cc/sec. or 8.57 gpm.
Least depth of water applied:	
Under low wind	7.42 mm/hr.
Under high wind	3.99 mm/hr.

Irrigation frequency:

Number of setting per day	2
Hours per settings	11, and 9 hrs.
Irrigating when	43.6 - 50 per cent of available water is used.

Climate:

Effective ppt.	155.40 mm.

Water to be applied by irrigation
per season .... 1276.46 mm.

Velocity of wind and its occurrance:

Normal .... from 6 p.m. to 1 p.m.

High .... from 1 p.m. to 6 p.m.

Direction of wind .... South-west.

According to the principle of least-cost-combination, a sprinkler system should be designed with due emphasis to its economic considerations. This is accomplished by selecting the components that do the effective job at least cost, and by reducing the capacity requirement of the system by operating it continuously for 11 hours per setting.

Systems designed to supply water for the peak use of crop will easily meet the lighter but more frequent irrigation requirements of the early stages of plant growth.

A portable system, using galvanized steel pipes and fittings, and consisting of a main and the required number of laterals will be designed here. The typical farm size used in the design is assumed to be 5 hectares in the area.

1. Depth of water applied in 11 hours at 7.42 mm/hr = 81.62 mm.
2. Irrigation interval = 81.62 ÷ 8.68 mm. water use/day=9.4 days.

In an arrangement of 2 settings per day, half a day means 1 setting. The 9.4 being less than 9.5 has to be rounded to 9 in order to give a regular irrigation interval.

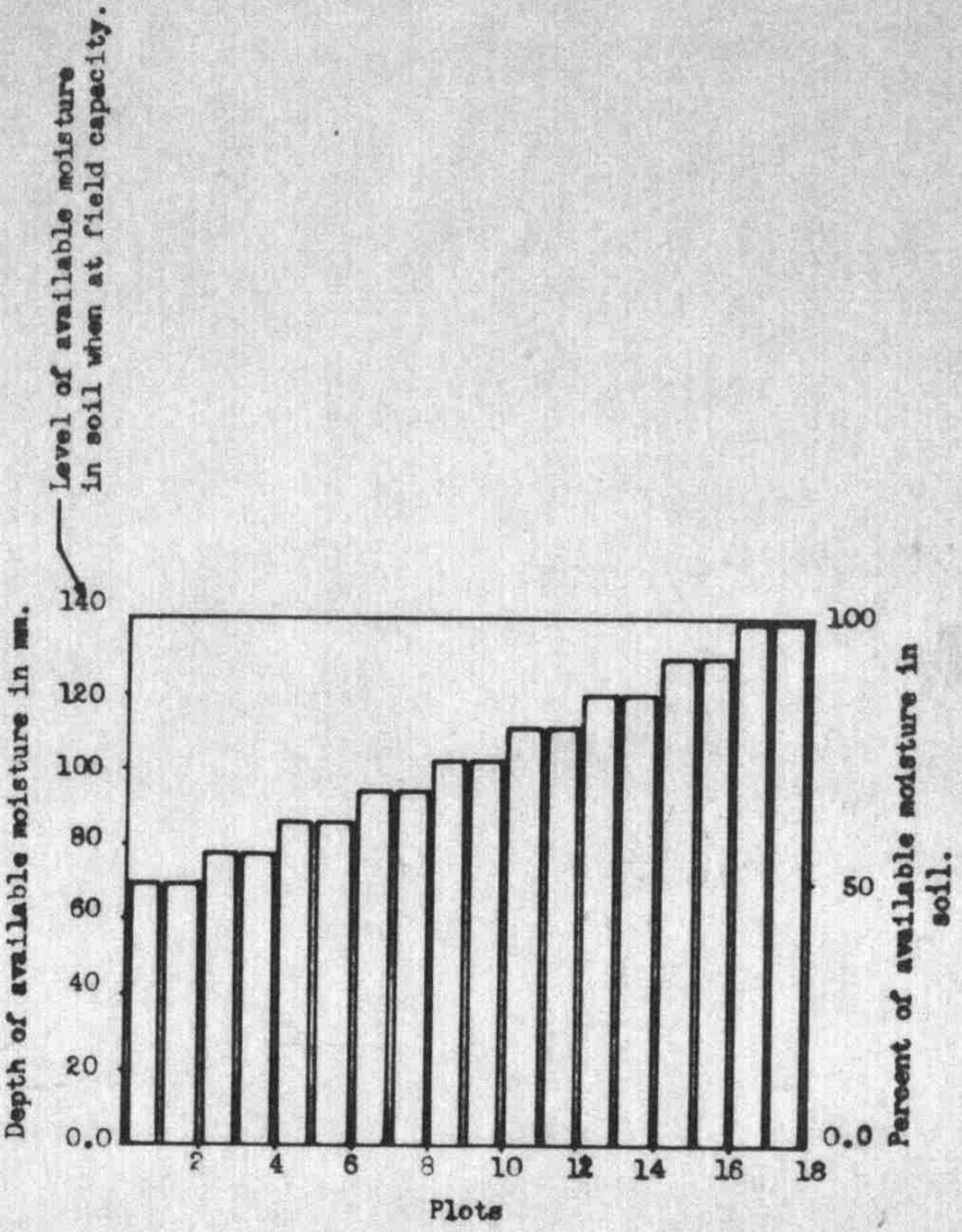
If the field is divided into 18 equal plots, and 2 plots are irrigated every day, 1 per setting, then by the end of the ninth day, the available moisture content in each plot will be as shown diagramatically in sketch 3. This shows the variation in available moisture to be from 100 to 50.4 per cent, which is satisfactory.

3. Laterals and sprinklers required. Taking the length as twice the width of the field, its dimensions will be 158 x 316 ms. With the main along the center of the field, the number of laterals required would be $\frac{316 \times 2}{9 \times 12 \times 2} = 3$ where 9 is the irrigation interval and 12 is the spacing of laterals. However, since sprinklers are to be 12 meters apart, it would be more advisable to lay the main not along the center of the field but 12 meters off to one side, as shown in sketch 4. This will reduce the number of required sprinklers by one. Then there will be 2 laterals with 7 sprinklers each and one with 6, or a total of 20 sprinklers.

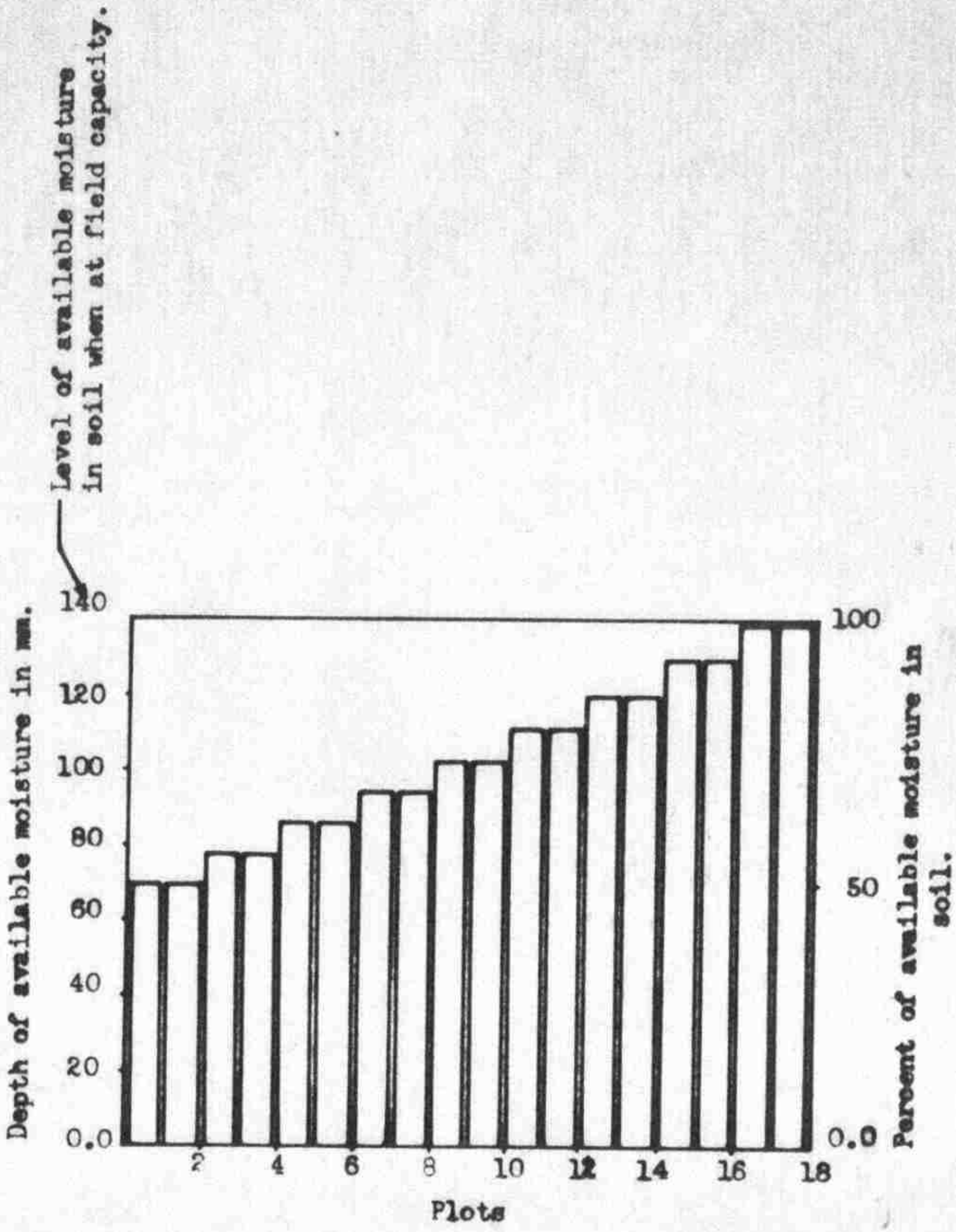
4. Capacity of the system. With 20 sprinklers discharging 8.57 gpm each, this will be 171.40 gpm.

5. Size of main line. In using 3 equal laterals, the area to be irrigated by each one will be one third of the total area. To avoid excessive friction losses and use of large size pipes all through, the laterals should be laid out as illustrated in sketch 4, rather than having 3 laterals close together. Sketch 4 further illustrates the condition when the friction loss in the main line is maximum.

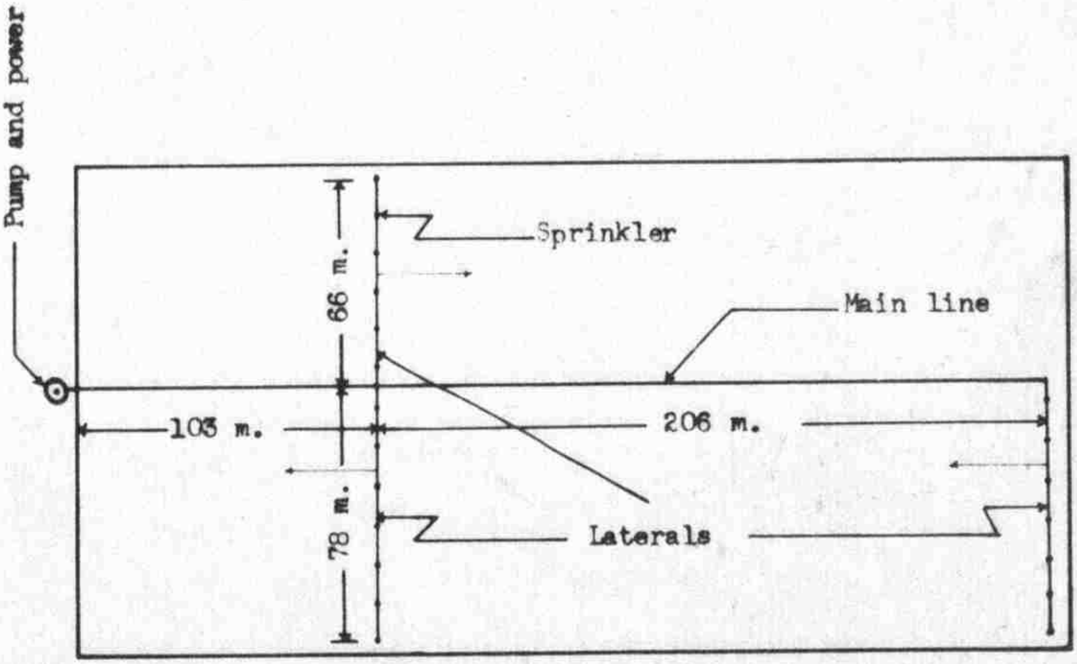
Two conditions should be observed in the selection of the size of the main line. First, the friction loss should not exceed 15 per cent of the pressure head or 6 psi. Second, the cost of the pipe should be kept to a minimum.



Sketch 3. Pattern of available moisture content of different plots in the field during the period of peak demand for water.



Sketch 3. Pattern of available moisture content of different plots in the field during the period of peak demand for water.



Sketch 4. Location of main line and position of laterals when friction loss is maximum.

Three alternate main size arrangements might be employed and should be evaluated for selecting the most suitable one.

a. Dividing the main into three equal parts, each with a different diameter.

b. Dividing the main into two parts, using a large diameter pipe for the first two thirds and a small diameter pipe for the remaining part.

c. Using the same diameter all through the main.

For the first case, we might use 108 mm. pipe for the first 103 ms., 89 mm. for the second and 70 mm. for the third. This gives a total friction loss of 5.46 psi and a cost of LL. 3658.40.

For the second case, we might use 89 mm. pipe for the first two thirds of the pipe and 70 mm. pipe for the remaining part. This gives a friction loss of more than 6 psi and is excluded.

For the third case, no detailed evaluation is necessary, because the study of the first case indicated that the only uniform size that would have a friction loss less than 6 psi would be one with a higher cost than that used there.

Therefore the pipe sizes of case "a" will be used.

6. Size of sprinkler lateral. Longer laterals carrying 7 sprinklers or 59.99 gpm require 50 mm. pipe in order to have a friction loss less than 20 per cent of the pressure head or 8 psi, the permissible friction loss in laterals. For a lateral carrying 6 sprinklers or 51.42 gpm, the diameter of pipe should also be 50 mm. because of the fact that the next lower size is 37 mm. and this does not carry a flow of more than 35 gpm. Friction loss in 50 mm. pipe is 4.04 psi.

7. Power required:

Capacity of pump = 20 x 8.57 = 171.40 gpm.

Delivery head:

Sprinkler head = 40 psi x 2.31 = 92.40 ft.

Suction head = 3 m. x 3.28 = 9.84 ft.

Friction loss in main = 5.46 psi x 2.31 = 12.61 ft.

Friction loss in lateral = 4.04 psi x 2.31 = 9.33 ft.

Friction loss in fittings, assumed = 0.82 ft.

Total delivery head = 125.00 ft.

Assuming a 70 per cent efficient pump, the diesel engine required will be $\frac{171.40 \times 125 \times 100}{3960 \times 70} \times 1.25 = 9.6$ hp, where 3960 is a factor which converts gpm into horsepower, and 1.25 is a factor when multiplied by bhp of electric motor gives the size of diesel engine required to operate the pump.

B. Cost of Sprinkler System for Five Hectares.

Table 26 shows the cost of the system designed to be operated under low or no wind conditions and satisfying the general design specifications established. From this we might establish the following annual fixed costs:

Main line	LL. 309.84
(Initial cost LL. 3863.40, life 20 years, and capital recovery factor 0.0802).	
Lateral line	LL. 58.26
(Initial cost LL. 1788.00, life 20 years, and CRF 0.0802).	

Sprinklers	LL. 58.26
(Initial cost LL. 376.60, life 8 years, and CRF 0.1547).	
Accessories	LL. 19.51
(Initial cost LL. 243.23, life 20 years, and CRF 0.0802).	
Pump and diesel engine	LL. 288.90
(Initial cost LL. 3000, life 15 years, and CRF 0.963).	
Tax and insurance at 2 per cent of average investment	LL. 92.71
Total	LL. 912.62

The annual variable costs would be the following:

Fuel cost (P52)	LL.1006.00
Lubricant and maintenance at 40 per cent of fuel cost	402.40
Repair of pipe lines and fittings at 3 per cent of their initial cost...........................	188.14
Labor cost for moving laterals at LL. 3.66 per hectare per irrigation	366.00
(Irrigation period is assumed to be 180 days from May first to the end of October. This means $\frac{180}{9}$ = 20 irrigations).	
Attendance for pump and engine at LL. 1.00 per hour per day	180.00
Total	LL. 2142.54

Thus the total annual cost of irrigation by sprinklers, under no or low wind conditions would amount to $\frac{912.62 + 2142.54}{5}$ or LL. 611 per hectare. This includes the cost of pumping water for sprinkling but

Table 26. Initial cost of a portable sprinkler system for an area of 5 hectares using steel pipes and fittings.

Component	Number	Diameter in mm.	Unit price in LL.	Total price in LL.
1. <u>Main line</u>				
Pipe in standard 6 m length	103/6 =17	108	92.60	1574.20
	17	89	70.60	1200.20
	17	70	52.00	884.00
Reducer	1	89	38.50	38.50
	1	70	27.00	27.00
Side outlet tee without valve	1	108	47.00	47.00
	1	89	41.50	41.50
	1	70	34.50	34.50
End plug	1	70	16.50	16.50
				3863.40
2. <u>Lateral line</u>				
Pipe in standard 6 m length	222 ÷6=37	50	41.80	1546.60
Riser	20	19	0.77	15.40
Sprinkler connecting clamp	20	50	5.00	100.00
Sprinkler	20	3/16"x3/32"	18.83	376.60
Pipe support leg	20	50	4.50	90.00
End plug	3	50	12.00	36.00
				2164.60
3. <u>Accessories</u>				
Strainer	1	70	80.00	80.00
Suction pipe 3 m long	1	70	27.50	27.50
90° bend	1	70	27.00	27.00
Discharge pump connection	1	70	28.52	28.52
Delivery connection curve	1	70	71.00	71.00
Pressure gauge	1		9.21	9.21
				243.23
4. <u>Pump and power</u>				
Centrifugal pump	1	75	500.00	500.00
Diesel engine	1		2500.00	2500.00
				3000.00
		Total initial cost		9271.23

does not include any charge for water itself. The water charge itself at 0.5 piasters per m^3 amounts to LL. 102.10 per hectare which increases the annual cost to LL. 713.10 per hectare.

In the following sections, attempt will be made to show how this figure might change under special conditions and how the existence of varying strong winds would increase it and by how much.

1. Variation of cost with kind of equipment. There are two kinds of equipment materials on the local market; galvanized steel and aluminum products. To determine which would result in a cheaper installation, a sprinkler system is designed, using aluminum pipes and fittings, for a typical farm and its cost is compared with that of a system with steel pipes and fittings.

Steel pipes are manufactured as straight pipes on which male and female parts should be welded, and clamps fixed on lateral pipes to hold risers and sprinklers. Aluminum pipes are manufactured as complete pipes with riser outlets and male and female couplings.

Lightness of aluminum pipes might be considered advantageous in saving energy and time in moving laterals. However, as was noticed in Lebanon, this was not a significant factor in reducing labor costs. Laborers hired to move laterals did not carry more aluminum pipes than they did with steel. This indicates that the major criterion for comparison between the two should be the annual fixed cost.

A sprinkler system for a 5 hectare farm, using aluminum pipes and fittings and assuming to operate under no or low wind conditions, will now be designed. Since the conditions are similar to those for which a system using steel products was designed, it is possible to use the same basic design elements and compute the size of aluminum pipes as follows:

Depth of water applied in 11 hours at 7.42 mm/hr. = 81.62 mm.

Irrigation interval = 81.62 ÷ 8.62 mm. water use/day = 9 days.

Number of laterals required .... = 3 lines.

Number of sprinklers required .... = 20

Capacity of the system .... = 171.40 gpm.

Selecting a main on the same principle as before, namely, initial cost and safe friction loss, it is found by trial and error, that a main of uniform 4 inch. in diameter is the most suitable. This will give a friction loss of 12.12 ft. and cost LL. 3478.20.

The size of lateral required to carry 7 sprinklers would be 2 inch-pipe, with a maximum friction loss of 10.14 ft.

The pump and power requirements would be the same as for the steel pipes.

Table 27 gives the details of the initial cost of such a system. From this we might establish the following fixed annual costs:

Main and lateral lines excluding sprinklers and accessories = LL. 703.45

(Initial cost LL. 7304.77, life 15 years and CRF 0.0963)

Sprinklers .... LL. 58.27

(Initial cost LL. 376.65, life 8 years and CRF 0.1547)

Accessories .... LL. 21.53

(Initial cost LL. 268.50, life 20 years, and CRF 0.0963)

Table 27. Initial cost of a portable sprinkler system designed for an area of 5 hectares using aluminum pipes and fittings.

Component	Number	Diameter in inch.	Unit price in LL.	Total price in LL.
Aluminum materials.				
1. Main line.				
Pipe in standard 20 ft. length.	51	4	68.20	3748.20
Side outlet tee without valve	3	4	51.15	153.45
End plug	1	4	17.05	17.05
				3918.70
2. Lateral line				
Pipe in standard 20 ft. with riser outlet	37	2	37.20	1376.40
Riser	20	3/4	0.77	15.40
Sprinkler	20	3/16 x 3/32	13.95	279.00
End plug	3	2	10.85	32.55
				1703.35
3a. Accessories.				
Discharge pump connection	1	3	28.50	28.50
90° bend	1	3	32.55	32.55
Pressure gauge	1		6.82	6.82
				67.87
Total 1+2+3a				5689.92
CIF and custom clearance 35 %				1991.50
Total cost of aluminum materials				7681.42
3b. Accessories.				
Strainer	1	3	80.00	80.00
Suction pipe 3 m. long	1	3	27.50	27.50
pipe support leg.	20	2	4.50	90.00
Delivery connection curve	1	3	71.00	71.00
				268.50
4. Pump and power				
Centrifugal pump	1	3	500.00	500.00
Diesel engine	1		2500.00	2500.00
Total initial cost				10949.92

Pump and diesel engine	LL. 288.90
(Initial cost LL. 3000.00, life 15 years, and CRF 0.0963)	
Tax and insurance at 2 per cent of average investment	LL. 109.50
	LL. 1181.65

Comparing the two systems, it is apparent that the cost variation is rather significant, using the prices available to the writer. The initial investment for the steel system was LL. 9271.23 ÷ 5 or LL. 1854.2 per hectare, while that of the aluminum is LL. 10949.92 ÷ 5 or LL. 2190.00 per hectare. The annual fixed costs are LL. 912.62 for the steel and LL. 1181.65 for the aluminum. Since operation or variable costs are the same, this shows that steel pipes are less expensive. It should be made clear at this point that if other prices were used this advantage might not be so significant.

2. Variation of cost with type of system. To evaluate the influence of the type of sprinkler system used on the annual cost of irrigation, two systems were compared; a solid system, employing no labor but with a complete coverage of pipes and sprinklers, and a portable one similar to that designed previously.

In designing the solid system, it was assumed that the same flow of water is available and the same irrigation interval would be followed. This design required crosses with valves which increase the cost of the system appreciably. Thus, the size of main and laterals and pumping unit will remain the same as those used for portable system.

Number of laterals required = $\frac{316 \text{ m} \times 2}{12 \text{ m.}}$ or 52 lines.

Total length of laterals according to sketch 4 will be

$$26 \times 78 + 66 = 3744 \text{ ms.}$$

Crosses to be used will be 103 ÷ 12 or 8 of 108 mm, 9 of 89 mm. and 9 of 70 mm.

Number of sprinklers to be installed will be

26 x 7 + 26 x 6 = 338 sprinklers.

There will be as many risers, sprinkler connecting clamps, and pipe support legs as there are sprinklers.

Table 28 shows the details of the initial cost of a solid system. From this initial cost we might establish the following fixed annual costs:

Main line excluding crosses	LL. 297.81
(Initial cost LL. 3713.40, life 20 years, and CRF 0.0802)	
Crosses	LL. 260.75
(Initial cost LL. 2707.72, life 15 years, and CRF 0.0963)	
Lateral lines excluding sprinklers	LL. 2420.31
(Initial cost LL.30178.46, life 20 years, and CRF 0.0802).	
Sprinklers	LL. 984.59
(Initial cost LL. 6364.54, life 8 years, and CRF 0.1547)	
Accessories	LL. 19.51
(Initial cost LL. 243.23, life 20 years, and CRF 0.0802)	
Pump and diesel engine	LL. 288.90
(Initial cost LL.3000.00, life 15 years, and CRF 0.0963)	
Tax and insurance at 2 per cent of average investment	LL. 462.07
Total annual fixed cost	LL. 4733.94

The annual variable costs would be as follows:

Fuel cost the same as for portable system	LL. 1006.00
Lubricant and engine maintenance at 40 per cent of fuel cost	LL. 402.40

Table 28. Initial cost of a solid sprinkler system on a rectangular area of 5 hectares.

Component	Number	Diameter in mm.	Unit price in LL.	Total price in LL.
1. <u>Main line</u>				
Pipe in standard 6 m. length	103÷6=17	108	92.60	1574.20
	17	89	70.60	1200.20
	17	70	52.00	884.00
Reducer	1	89	38.50	38.50
Cross	8	108	136.01	1088.08
	9	89	100.44	903.96
	9	70	79.52	715.68
End plug	1	70	16.50	16.50
				6421.12
2. <u>Lateral line</u>				
Pipe in standard 6 m. length	3744÷6=624	50	41.80	26083.20
Risers	338	19	0.77	260.26
Sprinkler connecting clamp	338	50	5.00	1690.00
Sprinkler	338	3/16"x3/32"	18.83	6364.54
Pipe support leg	338	50	4.50	1521.00
End plug	52	50	12.00	624.00
				36543.00
3. <u>Accessories</u>				
Strainer	1	70	80.00	80.00
Suction pipe 3 m. long	1	70	27.50	27.50
90° bend	1	70	27.00	27.00
Discharge pump connection	1	70	28.52	28.50
Delivery connection curve	1	70	71.00	71.00
Pressure gauge	1		9.21	9.21
				243.23
4. <u>Pump and power</u>				
Centrefugal pump	1	75	500.00	500.00
Diesel engine	1		2500.00	2500.00
				3000.00
			Total initial cost	46207.35

Repair of pipe lines and fittings at 3 per cent of their initial cost	LL. 1296.21
Attendance for pump and engine at 1 hour per day	LL. 180.00
Total	LL. 2884.61

Thus the total annual cost of the solid system with no charge for water would be 4733.94 + 2884.61 = LL. 7618.55 or LL. 1523.71 per hectare.

Comparing the two systems, it is apparent that due to the relatively low cost of labor and high cost of equipment, the portable system is much more economical than the solid one. The initial cost of the solid system is LL. 46207.35 ÷ 5 or LL. 9241.47 per hectare, while that of the portable one was LL. 9271.23 ÷ 5 or LL. 1854.24. The annual cost of the solid system is LL. 1523.71 while that of the portable one was LL. 611.00.

3. Variation of initial cost with size of area irrigated. The purpose of this section is to study the variation in the initial cost of sprinkler systems as the size of the area irrigated changes. To achieve this, increasing sizes of farm plots varying from 2.5 to 40 hectares are considered and a sprinkler system designed for each. Then the initial costs are compared on a per unit area basis. All areas will be assumed rectangular with length equal to twice the width, and with similar physical conditions of soil, crop requirements, etc...

Table 29 shows the various elements considered in the design of each system and the sizes required for each plot.

Table 30 shows the initial cost of each item specified in table 29.

Table 29. Design of portable sprinkler systems for various farm sizes

Item	Farm size in hectares				
	2.5	5	10	20	40
Irrigation frequency	9 days	9 days	9 days	9 days	9 days
Number of laterals	2	3	4	6	8
Total length of laterals	108 m.	222 m.	408 m.	900 m.	1728 m.
Number of sprinklers	10	20	36	78	148
Capacity of system in gpm	85.7 gpm	171.40	307.52	668.46	1268.36
Size of laterals in mm	50	50	70	89	108
Total length of main line in m.	216	306	438	630	894
Size of the first third or half of main	70 mm	108 mm	133 mm	200 mm	300 mm
Size of the middle third of main	--	89 mm	--	159 mm	--
Size of the last third or half of main	70 mm	70 mm	108 mm	108 mm	250 mm
Diesel engine required in Hp.	4.4	9.6	17.4	37.6	71.5

The initial cost per hectare seems to decrease with an increase in size of area up to 10 hectares but increases after that. This indicates that, given the prices considered existing in 1964 on the local market, the most economical size of land to be sprinkler irrigated lies somewhere between 5 and 15 hectares. The disproportionate increase in cost for the larger areas is due to the fact that the prices of the components of the systems do not vary proportionally with the size. By doubling the size, the per unit prices of certain pieces of equipment such as pipes increase more than twice, while the others remain the same or increase but little. Comparison of the prices of pipes in table 18 and their total cost in table 30 indicate that the initial cost of these for 40 hectares is much more than double those required for 20 hectares and those of 20 hectares more than double those used for 10 hectares.

Table 30. Initial cost of portable sprinkler systems for various rectangular farm sizes in LL.

Components	Values of items for each farm size in LL.				
	2.5 ha.	5 ha.	10 ha.	20 ha.	40 ha.
1. <u>Main line</u>					
Pipe in standard 6 m. length	1872.00	3658.40	8268.20	17471.00	47573.00
Reducer	-	65.50	53.00	67.00	134.00
Side outlet tee without valve	69.00	123.00	202.00	310.00	616.00
End plug	16.50	16.50	28.00	28.00	48.00
2. <u>Lateral line</u>					
Pipe in standard 6 m. length	752.40	1546.60	3536.00	10590.00	26668.80
Riser	7.70	15.40	55.80	120.90	229.40
Sprinkler connecting clamp	50.00	100.00	180.00	390.00	740.00
Sprinkler	188.30	376.60	677.88	1468.74	2786.84
Pipe support leg	67.50	90.00	243.00	546.00	1110.00
End plug	24.00	36.00	66.00	132.00	224.00
3. <u>Accessories</u>					
Strainer	80.00	80.00	110.00	125.00	150.00
Suction pipe 3 m. long	23.00	27.00	50.00	73.00	100.00
90° bend	22.00	27.00	50.00	68.00	113.00
Discharge pump connection	23.25	28.52	49.60	61.07	80.00
Delivery connection curve	58.00	71.00	127.00	173.00	242.00
Pressure gauge	9.21	9.21	9.21	9.21	9.21
4. <u>Pump and power</u>					
Centrifugal pump	410.00	500.00	720.00	920.00	1200.00
Diesel engine	1680.00	2500.00	3540.00	5940.00	11280.00
Total initial cost	5352.86	9271.23	17965.69	38492.92	93304.25
Initial cost per hectare	2141.14	1854.25	1796.57	1924.65	2332.68

<u>N.B.</u> When pipe size had no published price, a price was assumed on the basis of weighted linear relation with available prices.

If the initial cost values are plotted, and a smooth curve fitted to them, as in figure 4, it might be deduced that 12 hectares is the most economical size of farm to irrigate by sprinklers. This result is not what would generally be expected under the hypothesis of large scale reductions in cost. One significant factor should be singled out here, and that is with the larger areas, significant economies could be accomplished by replacing the main pipes by permanent asbestos cement pipes which are much cheaper and just as durable. Such replacement was not considered within the scope of this study.

C. Evaluation of the Effect of Wind on Irrigation by Sprinklers.

Farmers using sprinklers in the Bekaa would face three alternatives in attempting to reduce the adverse effects of strong varying winds on the efficiency of their operation. The first alternative would be to stop irrigation during the periods of high wind. The second would be to use a different layout for periods of high wind compared to that of low or no wind. The third would be to operate the system with no regard to the wind conditions, but compensate for the distorted distribution pattern by increasing the time of set, reducing the irrigation interval or by increasing the size of the sprinkler equipment.

In evaluating the effect of wind on the cost of irrigation by sprinklers, the cost of doing a certain irrigation job under conditions of no wind is compared with the cost of achieving the same results under the assumed wind conditions. However, only two alternatives will be evaluated. The alternative of changing layouts whenever strong winds

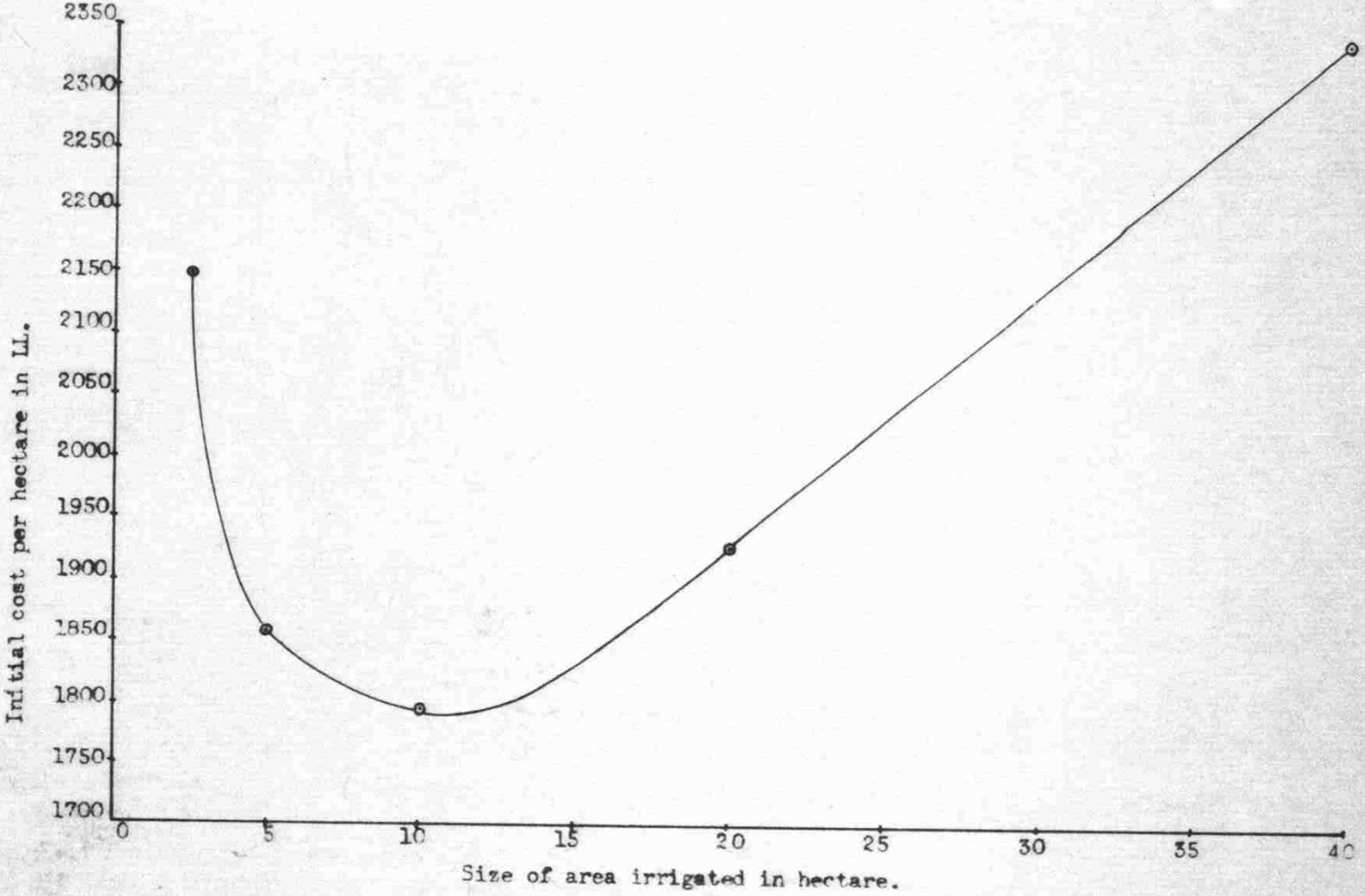


Figure 4. Variation of initial cost of sprinkler system with size of area irrigated.

tend to blow seemed too impractical to consider. Furthermore, when operating continuously, only the alternative of reducing the irrigation interval, while keeping the time of set and the size of equipment the same as before, was considered.

When the system is used only during periods of low or no winds, the operation time becomes limited to 2 settings a day, each 9 hours, provided that the setting is so timed that 1 moving of laterals is accomplished during the high wind period. Working within the limit of practicability, the most feasible arrangement will be to start the first setting at 4 a.m., finish it by 1 p.m., and start the second at 6 p.m., and finish by 3 a.m. Since it is not possible to increase the rate of application in order to apply in 9 hours the same quantity of water that would be applied in 11 hours because of the limitation set by the soil infiltration rate, it is necessary to keep the application rate constant during the 9 hour irrigation period and to shorten the interval between irrigationsand increase the area irrigated per setting. This alternative would require more laterals in order to cover a larger area with each setting than that would be needed in 11 hours of irrigation per setting. This extra equipment cost together with relatively higher labor charge would represent the effect of wind on the cost of irrigation by sprinklers.

When the system is used all day long, the least application rate during the 5 hours of high wind which is 3.99 mm per hour (table 12) is equal to $\frac{3.99 \times 100}{7.42}$ or 53.8 percent of the least application rate during low wind conditions. If the setting is so timed that one hour of high wind is spent in moving laterals, then 2 hours of operation of the system would be under high wind conditions per setting. This will be equivalent to $\frac{2 \times 53.8}{100}$ or 1.07 hours of operation of the system under low wind conditions. So even though the irrigation period is 11 hours per setting, 9 hours under low wind and 2 hours under high, the total effective depth of water applied will be just equivalent to that applied in 9 + 1.07 or 10.07 hours under low wind conditions. A sprinkler system operated 10.07 hours per setting requires less frequent irrigation and less equipment than the one operated 9 hours per setting. Therefore this alternative will be more economical than the one operated only under low wind conditions, if the cost of water lost during the 2 hours of operation per setting under high wind conditions does not over-balance it. The cost of water loss may be calculated as follows:

Water discharged from sprinkler system is equal to $\frac{171.40 \text{ gpm} \times 60 \times 3.7853 \text{ lit/gal.}}{1000}$ or 38.93 m^3 per hour. This when multiplied by 17 settings per irrigation will amount to 661.81 m^3. Therefore the water loss during the 2 hours of strong wind would be $(2 - 1.07) \times 661.81 = 617.48$ m^3 per irrigation or $\frac{180}{8.5}$ days x 617.48 = 12967.1 m^3 per season, and the cost of it at 0.5 piasters per m^3 would be LL. 64.84 or LL. 12.97 per hectare.

With this general background, each system will now be designed and evaluated in detail.

1. Interrupted operation of sprinkler system.

a) Depth of water applied = 9 x 7.42 = 66.78 mm.

b) Irrigation interval = 66.78 ÷ 8.68= 7.5 days, that is, 2 irrigation should be completed in 15 days. Since 2 settings are made a day; on the eighth day one setting will be for the end of the first irrigation period, and the other one for the beginning of the second irrigation period. With this interval, the available moisture level will fall from 100 per cent to $\frac{[140 - (8.68 \times 7)]100}{140} = 56.4$ per cent which is above the safe limit.

c) Number of laterals required. $\frac{316 \times 2}{7.5 \times 12 \times 2} = 3.5$ laterals.

Since it is not possible to deliver water by half lateral from main line to the border of the field, one of two alternatives has to be adopted.

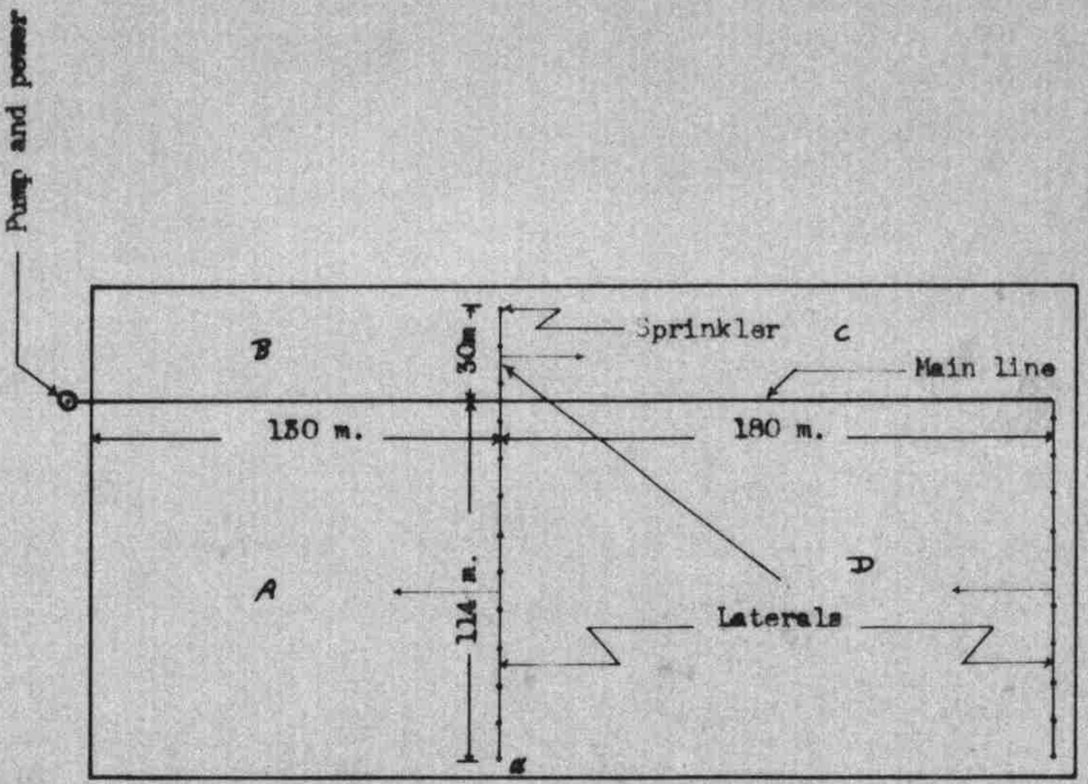
(1) To use 4 laterals which finishes the irrigation of the entire field in less than 7.5 days but require more pipes, more sprinklers and larger pumping unit, and is not economical.

(2) To displace the main from the center line of the plot. In this case, as is shown in sketch 5, there will be 2 long laterals each with 10 sprinklers and 1 short one with 3 sprinklers. The area to be irrigated by each of the two long laterals will be $5000 \times \frac{10}{23} = 21,740$ m^2. The width of area being irrigated by each long lateral is 10 x 12 = 120 ms. Therefore the second lateral has to start from a distance of 21,740÷120 = 180 ms. away from the first lateral. The other approach is by multiplying the width of area sprinkled by one lateral by 7.5 x 2 to give the starting point of the second lateral as 7.5 x 2 x 12 = 180 ms.

d) Number of sprinklers required will be 23.

e) Capacity of the system will be 23 x 8.57 or 197.1 gpm.

f) Size of main line:



Sketch 5. Location of main line and position of laterals when friction loss is maximum.

Under the set up producing the greatest discharge requirement of the main, shown in sketch 5, the first 130 meters have to carry the total Q, while the remaining 180 meters should carry $\frac{10}{23}$ Q. Under this set up, 133 mm. pipe would be used for the first part and 89 mm. pipe for the remaining. This would produce a friction loss not exceeding that allowed in normal design.

g) Size of sprinkler laterals. The permissible friction loss in laterals is 20% of 8 psi. A 70 mm. pipe carrying 10 x 8.57 = 185.7 gpm will have a friction loss equal to $\frac{114}{100} \times \frac{3.3}{10} \times 14.2 \times .39 = 1.77$ psi. For 50 mm. pipe, the friction loss is $\frac{114}{100} \times \frac{18}{10} \times 14.2 \times 0.39 = 11.36$ psi, which is larger than 8 psi, and can not be used. For the short lateral carrying 3 x 8.57 = 25.71 gpm a 37 mm. pipe with a friction loss equal to $\frac{30}{100} \times \frac{10}{10} \times 14.2 \times 0.52 = 2.42$ psi will suffice but is not available in the local market, so 50 mm. pipe will be used.

h) Diesel power required.

Capacity of pump 197.1 gpm.

Delivery head:

Sprinkler head = 40 x 2.31 = 92.40 ft.

Suction head = 3 x 3.28 = 9.84 ft.

Friction loss in main = 6 x 2.31 = 13.86 ft.

Friction loss in lateral = 1.77 x 2.31 = 4.09 ft.

Friction loss in fittings = 1.81 ft.

Total = 122.00 ft.

$$\frac{197.1 \times 122 \times 100}{3960 \times 70} \times 1.25 = 10.75 \text{ hp.}$$

Table 31 shows the details of the initial cost of the sprinkler system designed to operate during the periods of low wind only. From this we may establish the following fixed annual costs.

All parts except sprinklers and pump with power	LL. 656.04
(Initial cost LL 8180.00, life 20 years, and CRF 0.0802)	
Sprinklers	LL. 67.00
(Initial cost LL. 433.09, life 8 years, and CRF 0.1547)	
Pump and diesel power	LL. 288.90
(Initial cost LL.3000.00, life 15 years, and CRF 0.0963)	
Tax and insurance at 2 per cent of average investment	LL. 116.13
Total	LL. 1128.07

The cost of fuel, lubricants, engine maintenance and attendance for pump and engine are the same as those determined for system operating under no or low wind conditions as :

1006.00 + 402.40 + 180.00 or	LL. 1588.40
Repair of pipe line and fittings at 3 percent of their initial cost	LL. 258.40
Labor cost for moving laterals at LL 3.66/ha/irrigation will be 180 days + 7.5 days as irrigation interval	LL. 439.20
Total	LL. 2288.00

Thus the total annual cost of irrigation by sprinklers, under interrupted operation, that is, operating the system only during the periods of no or low winds would amount to $\frac{2288.00 + 1128.07}{5}$ or LL.683.20 per hectare. This includes the cost of pumping water for sprinkling but does not include any charge for water itself. The water charge itself

Table 31. Initial cost of the system designed for a rectangular area of 5 hectares and operated only during the periods of low wind conditions.

Component	Number	Diameter in mm.	Unit price in LL.	Total price in LL.
1. Main line				
Pipe in standard 6 m. length	130÷6=22	133	134.50	2959.00
	180÷6=30	89	70.60	2118.00
Reducer	1	89	38.50	38.50
Side outlet tee without valve	3	133	54.00	162.00
	2	89	41.50	83.00
End plug	1	70	16.50	16.50
				5377.00
2. Lateral line				
Pipe in standard 6 m. length	228÷6=38	70	52.00	1976.00
	30÷6= 5	50	41.80	209.00
Riser	20	25	1.55	31.00
	3	19	0.77	2.31
Sprinkler connecting clamp	20	70	5.00	100.00
	3	50	5.00	15.00
Sprinkler	23	3/16"x3/32"	18.83	433.09
Pipe support leg	20	70	6.75	135.00
	3	50	4.50	13.50
End plug	4	70	16.50	66.00
	1	50	12.00	12.00
				2992.90
3. Accessories				
Strainer	1	70	80.00	80.00
Suction pipe 3 m. long.	1	70	27.50	27.50
90° bend	1	70	27.00	27.00
Discharge pump connection	1	70	28.50	28.50
Delivery connection curve	1	70	71.00	71.00
Pressure gauge	1		9.21	9.21
				243.23
4. Pump and power				
Centrifugal pump	1	75	500.00	500.00
Diesel engine	1		2500.00	2500.00
				3000.00
		Total initial cost		11613.13

at 0.5 piasters per m^3 amounts to LL. 102.10 which increases the annual cost to LL. 1785.30 per hectare.

2. Continuous operation of sprinkler system.

a) Depth of water applied = 10.07 x 7.42 = 74.72 mm.

b) Irrigation interval = 74.72 ÷ 8.68 = 8.6 days.

Since there are 2 settings per day, it is quite possible to have an irrigation interval of 8.5 days and finish 2 irrigations in 8.5 x 2 = 17 days. With this irrigation interval, the available moisture level of the last portion of the field to be irrigated on the nineth day will drop to $\frac{[140 - (8 \times 8.68)]100}{140}$ = 50.4 per cent which is above the safe limit.

c) Number of laterals required.

$$\frac{316 \times 2}{8.5 \times 12 \times 2} = 3 \text{ laterals}$$

This shows that the equipment requirement will be the same as that designed for low or no high wind conditions. However there will be greater number of lateral movements and greater water loss than that encountered in the system operated under no high wind conditions for 11 hours per setting. Therefore the initial cost and fixed costs will be the same as that calculated for the typical system operating under low or no wind conditions. The variable costs will be as follows:

Costs of fuel, lubricant, engine maintenance, and repair of pipe lines and fittings as those on page 62 as LL.1596.54

Cost of pumping water lost at 1.9 piasters per m^3 =
12967.1 m^3 x 1.9 = ... LL. 246.37

Labor cost for moving laterals at LL. 3.66/ha/irrig. = LL. 402.60

Attandance for pump and engine at LL. 1/hr. .... = LL. 180.00

Total LL.2425.50

Thus the total annual cost of irrigation by sprinklers under continuous operation will be $\frac{2425.51 + 912.62 \text{ (fixed costs)}}{5}$ or LL. 667.62 per hectare. This includes the cost of pumping water for sprinkling but does not include any charge for water itself. The water charge itself at 0.5 piasters per m^3 amounts to 102.10 + 12.97 = LL. 115.07 per hectare. This increases the annual cost to LL. 782.70 per hectare.

Table 32 was prepared to evaluate the two alternatives by comparing their costs with those of sprinkling under no or low wind conditions. Two cases were taken into account; first assuming water to be free and second assuming it to cost 0.5 piasters per m^3. From this comparison it is apparent that under both conditions, the second alternative, that is, operating the sprinkler systems continuously for 22 hours a day, 11 hours per setting, under low and high wind conditions is more economical than the first one where the system is operated only under low wind conditions. When water is free, the annual per hectare cost of the second alternative is higher than that of the check by 11.2 per cent, while that of the first alternative is higher by 13.6 per cent. These extra costs reflect the effect of wind on irrigation by sprinklers. When water is not free and has a value of 0.5 piasters per m^3, the annual per hectare cost of the second alternative is higher than that of the check by 10 per cent, while that of the first alternative is higher by 10.11 per cent. The extra cost of the first alternative is due mainly to extra equipment needed to accomplish the same job in 9 hours that would be accomplished by less equipment in 11 hours. The extra cost of the second alternative is due mainly to the cost of water lost during the 2 hours of operation of sprinkler systems per setting under high wind conditions.

It should be pointed out that the annual per hectare cost of irrigation by sprinklers would increase more than what is determined above, due to the effect of wind, if the varying high winds were found to occur more than 5 hours a day in the Bekaa area.

Table 32. Comparative costs of irrigation by sprinklers

Item	Alternatives designed and evaluated		
	Check-operated continuously under no or low wind conditions.	1st alternative operated only under low wind conditions	2nd alternative operated continuously under low & high wind conditions
1st. Water is free			
Initial cost for 5 hectares	LL 9271.20	LL 11613.10	LL 9271.20
Annual fixed costs for 5 hectares	912.60	1128.10	912.60
Variable costs for 5 hectares	2142.60	2288.00	2425.50
Total annual costs for 5 hectares	3055.10	3416.10	3338.10
Annual cost per hectare	611.00	683.20	667.60
Comparative cost as per cent	100.00	113.60	111.20
2nd. Water costs 0.5 piasters per m^3			
Initial cost for 5 hectares	LL 9271.20	LL 11613.10	LL 9271.20
Annual fixed costs for 5 hectares	912.60	1128.10	912.60
Variable costs without water for 5 hectares	2142.60	2288.00	2425.50
Water charge for 5 hectares	510.50	510.50	575.35
Total annual cost for 5 hectares	3565.70	3926.60	3913.45
Annual cost per hectare	713.10	785.30	782.70
Comparative cost as per cent	100.00	110.11	110.00

SUMMARY AND CONCLUSION

The purpose of this study was to determine the effect of wind on the cost of irrigation by sprinklers. Before accomplishing this, the general strong and weak points of sprinkler irrigation were expressively evaluated and different types of sprinkler systems were discussed. Then an attempt was made to establish the basic design specifications for sprinkler systems. In doing so, available data regarding the following items were determined or assumed: water holding capacity of soil, infiltration rate of soil, consumptive use of water by the crop to be grown, irrigation frequency and efficiency, conditions of winds prevailing in the Bekaa area, effective precipitation, quality and quantity of water available, and slope and shape of the land to be irrigated. Labor requirements were determined by actual observation of time spent by laborers in moving laterals in different farms in Lebanon. Water charges were calculated on 2 bases; first assuming it to be available in liberal quantities at shallow depths where its cost was just the cost of pumping it, and second assuming it to be available in limited quantities with its value represented by the differential benefit resulting from dry and irrigated land.

Using the same application rates that Mutayreh (35) had obtained in his experiment regarding the effect of wind on sprinkler performance, triangular layouts were also evaluated to determine their effectiveness in overcoming the adverse effect of wind on distribution patterns.

Finally a sprinkler system was designed with a 12 x 12 m. square layout, using galvanized steel pipes and fittings, to operate continuously under no or low wind conditions on a typical rectangular farm of 5 hectares in size. Its initial and annual costs were determined. Variations of these costs with kind of equipment, type of system, size of irrigated area, and strong winds occuring assumably for 5 hours during the afternoons in the Bekaa area were evaluated.

Based on the above study, the following general conclusions could be drawn:

1. Contrary to what some workers have suggested, layout pattern does not seem to have a significant influence on overcoming the adverse effect of high wind on the performance of sprinklers. It is the spacing rather than the pattern that levels out the irregularities in distribution of water discharged from sprinklers under a given pressure (40 psi.)

2. Using 3/16" x 3/32" - 7^{0} sprinkler with 40 psi of pressure on a medium textured soil with maximum infiltration capacity of 12.7 mm. per hour, a 12 x 12 m. square layout provides the highest uniformity coefficient and can be used satisfactorily.

3. The initial and annual costs of typical sprinkler system , formed of galvanized steel pipes and fittings, and operating continuously under no or low wind conditions on a rectangular area of 5 hectares, were found to be LL. 9271.20 and LL. 3055.10 respectively. This gives an annual cost of LL. 611.00 per hectare. When water was limited and had a

value of 0.5 piasters per m^3, the annual cost increased to LL. 3565.70 for 5 hectares or LL. 713.10 per hectare.

4. The initial and annual fixed costs of sprinkler system, formed of aluminum pipes and fittings, under the prevailing prices on the market in Lebanon, were higher than those formed of steel pipes and fittings by 18.1 and 29.5 per cent respectively.

5. Due to the relatively low labor cost in Lebanon, it was found to be more economical to use portable sprinkler systems rather than solid ones. The initial cost of solid systems where laterals and main are set permanently for one growing season of the crop was prohibitively high and its annual cost per hectare was 138 per cent more than that encountered in using portable systems.

6. Initial cost of sprinkler systems decreased with increase in size of irrigated area up to a certain limit and then increased. As is seen from figure 4, the optimum area for the installation of a sprinkler system is 12 hectares and the relatively economical range lies between 5 and 15 hectares. It should be pointed out that economies of scale might be achieved if the main steel pipes on large farms were replaced by under ground asbestos cement pipes which are cheaper and just as satisfactory.

7. Farmers in the Bekaa area might adopt one of two alternatives for reducing the adverse effect of varying strong winds on the performance of sprinklers; the first is to operate their sprinkler systems only during the periods of low wind and the second is to use the systems continuously

under low and high winds. From the comparison of the annual per hectare costs of these two practical alternatives, it can be concluded that the second alternative is more economical than the first one. When water is free and available in liberal quantities, the annual per hectare cost of the second alternative is higher by 11.2 per cent than that of the system operated continuously under no or low wind conditions, while that of the first alternative is higher by 13.6 per cent. When water is limited and has a value of 0.5 piasters per m^3, the annual per hectare cost of the second alternative is higher than that of the system operated under no or low wind conditions by 10 per cent, and that of the first alternative is higher by 10.11 per cent. These extra costs reflect the effect of wind on irrigation by sprinklers. The extra cost of the first alternative is due mainly to extra equipment needed to accomplish the same job in 9 hours that would be accomplished by less equipment in 11 hours. The extra cost of the second alternative is due mainly to the cost of water lost during the 2 hours of operation of sprinkler systems per setting under high wind conditions.

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