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Evaporation and Drift Losses from Sprinkler Irrigation Systems under Hot and Dry Conditions

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Abstract. Evaporation and wind drift losses from sprinklers under different combinations of climatic and operating conditions were determined. Results show that losses vary inversely with diameter of the nozzle and relative humidity and approximately proportional to air temperature, wind velocity and operating pressure.

The evaporation loss model indicated that sprinkler evaporation and drift losses are most directly related to the nozzle size, relative humidity and air temperature respectively.

Introduction

Sprinkler irrigation is a cultural practice that occurs on a large scale and utilizes limited and expensive resources of water and energy. As the necessity for conservation of water resources increases, especially in areas of limited water supply and under desert conditions, more precise knowledge about application efficiencies of sprinkler irrigation systems is required. Therefore, more efficient use of irrigation will be based on better designed and management. Irrigation principles and practices for sprinkler irrigation have been advanced to the point that water application efficiency is significantly influenced by the amount of evaporation and wind drift losses. More knowledge about water losses associated with sprinkler irrigation can significantly help towards assessing the overall application efficiency. Increasing irrigation efficiency can be instrumental in raising crop production because a larger area can be irrigated with the same volume of water, or a water shortage can be made less severe.

In most sprinkler irrigation operations, part of the water leaving the nozzles evaporates before it reaches the ground. In windy conditions some of the spray droplets are carried out from the target application area, thereby reducing the efficiency of sprinkler irrigation. These losses in desert areas may amount to a high proportion of the total water applied. This high loss of irrigation water is critical in areas with a limited water supply. It is reported in the literature that the magnitude of evaporation and drift losses depends upon both the sprinkler system parameters, such as nozzle size and operating pressure and the climatic parameters, such as air temperature and wind velocity, etc. Therefore, it would be of considerable value to designers of sprinkler systems to draw attention to the most important parameters affecting the losses and advantageous to find ways to reduce evaporation and drift losses during irrigations to conserve water and energy.

Sprinkler irrigtion evaporation losses have been the subject of numerous field, laboratory, and analytical studies. A wide range of losses has been reported in the literature due to the many physical and climatic parameters involved. Many investigators have lumped losses due to evaporation and spray drift together into spray losses. This approach has been used largely because of difficulties with the measurements techniques necessary to separate these losses. Frost and Schwalen [1] used the catch-can method and found that variations in losses were approximately proportional to wind velocity and operating pressure, and inversely proportional to nozzle size and relative humidity of the air. They obtained good correlation between spray losses and vapor pressure deficit. Kraus [2] found that total evaporation losses ranged from 3.4 to 17%, and 36% of the total loss was due to drift. Sternberg [3] concluded that drift losses were 60% of the total evaporation loss.

Hermsmeier [4] determined evaporation losses from sprinklers using in the electrical conductivity measurements of the water caught in the catch containers and the water supply. He found that evaporation loss can range from 0 to 50% or more of the water applied over short periods of time. He stated that evaporation losses from sprinklers are more closely related to air temperature and rate of application than to wind speed or relative humidity. Seginer and Kostrinsky [5] found that spray evaporation was negligible relative to drift loss. Heerman and Kohl [6] gave the range of evaporation loss from 1 to 6% of the total water applied from several calculations. Ali and Barefoot [7] measured evaporation losses of 48%. They concluded that relative humidity and air temperature were the most significant factors influencing the evaporation losses. Yazar [8] found that evaporation losses ranged from 1.5 to 16.8% of the total water applied. He concluded that wind speed and vapor pressure deficit were the most significant factors affecting the losses, and that drift losses varied from 1.5 to 15.1% of the total water applied. Kohl, *et al.* [9] reported that evaporation losses from spray nozzles ranged from 0.4 to 1.4%. Also, research has shown that small droplets are more susceptible to evaporation and wind drift e.g., Thompson *et al.* [10]. Representatives of the sprinkler irrigation industry indicate that 10 to 25% of the water leaving the sprinkler is lost between the sprinkler nozzle and the crop canopy [9]. They attributed this loss to a combination of spray evaporation and wind drift.

The objectives of this study were:

1. To determine evaporation and wind drift losses from different sizes of impact sprinklers; and
2. To develop an empirical relationship of the losses expressed as a function of different variables which influence it.

Materials and Methods

The field studies of this paper were conducted at the educational farm of the College of Agriculture, King Saud University, Riyadh, during the period of April through July 1991.

A series of tests were made using a single stationary sprinkler system (Fig. 1-a) to determine the evaporation losses, and the effect of sprinkler system parameters such as nozzle size and operating pressure, and the climatic parameters such as air temperature, wind velocity and relative humidity on the quantity of evaporation losses. Also, the effect of distance from the sprinkler on evaporation was investigated.

Ten types of the commercial impact sprinkler of different nozzle sizes that are commonly used for field irrigation were selected for this study. Each sprinkler type was mounted on 1.0 m. riser above the ground surface, with a pressure gauge installed on it. Three sprinklers from each type were used for each test. The system was then operated at three operating pressure levels of 200, 250, 300 kPa. Catch cans of cylindrical metal, 100 mm diameter and 115 mm height were placed on both sides of the lateral at a spacing of 1.0 m. on a level ground surface. The layout of the sprinkler system used in the study is shown in Fig. 1.

Flow rates, wind direciton, velocity, dry-wet bulb temperature and relative humidity were continuously recorded during each test. Nozzle pressure was measured with a pressure gauge attached to the riser. The system was operated for a duration of 1 to 2 hours for each run, depending on the nozzle size in order to collect a sufficient amount of water in the catch cans.

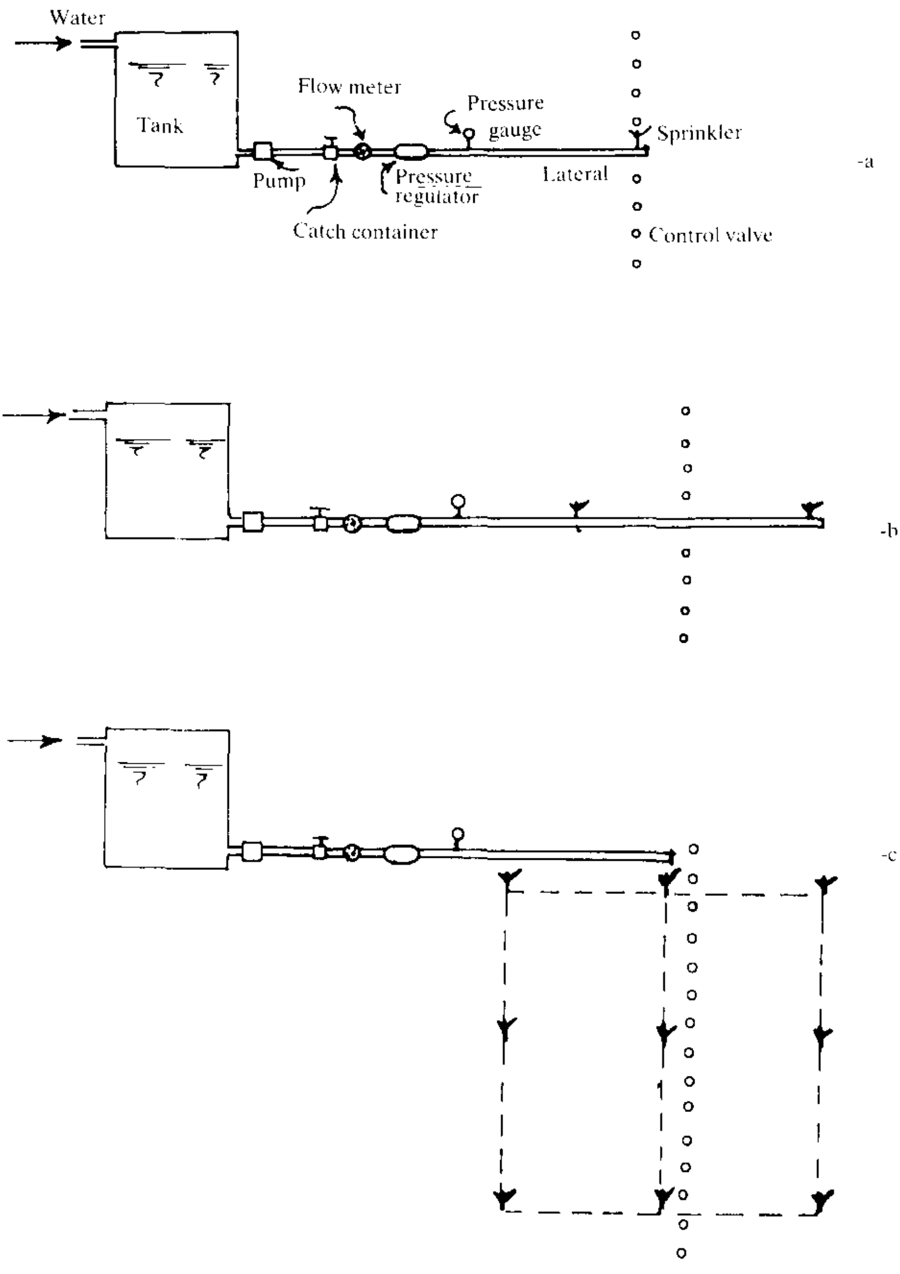

Fig. 1. Field layout of the apparatus used in the study.

The sprinkler evaporation loss has been computed from:

$$E = [(Q1 - Q2)/ Q1] \times 100 \%$$

where:

E = sprinkler evaporation and wind drift losses (%)
Q1 = discharge from sprinkler nozzle
Q2 = discharge reaching catch cans

To determine the amount of evaporation that would occur from the catch cans during the test period and after end of the test and before measurements, an additional three catch cans were used with a premeasured quantity of water during the preceding test, and were placed outside the vicinity of the sprinkler spray. Volumes in these catch cans were recorded at the end of the experiment, and also at the end of reading of all the catch cans.

To determine the effect of distance from the sprinkler on evaporation and drift losses, the electrical conductivity values of the water supply and the water collected in the catch cans were measured. Then the evaporation and drift losses were computed from the ratio of the salt content of water caught in a sprinkler area to the salt content of the supply water. Spray losses based on ratio of depth of caught water to average application depth did not prove satisfactory, because this method was affected by both spray losses and the water distribution pattern from sprinklers. Previous tests had shown that non-uniformity of the sprinkler distribution pattern commonly has a greater effect on the quantity of water caught than on the evaporation and drift losses.

Also, to simulate field conditions, and to compare spray losses from a single sprinkler with those occurring with overlapping sprinklers, a number of tests were conducted in which two sprinklers (Fig. 1-b), and a permanent sprinkler system (Fig. 1-c) were operated and the losses were computed on the basis of the overlapping area between the sprinklers.

The losses in this study have been considered as the sum of evaporation and wind drift losses, which occurred between the sprinkler nozzles and the ground surface. Correction for the evaporation losses which occurs after the water reaches the catch cans has been made.

Results and Discussions

A series of tests were made with a single nozzle or double nozzle sprinklers under field conditions to determine the evaporation and wind drift losses. The average results of the spray losses, the climatic and operation parameters are presented in Table 1. The average losses ranged from 75.5% for a single nozzle of 2.29 mm diameter to 22.6% for double nozzle sprinkler of diameter 6.1 × 3.0 mm. The spray losses from sprinklers varied widely between the tests. This may be related to changes in climatic parameters during the tests. In general the results indicated that evaporation and drift losses decreased with increasing the nozzle size or with double nozzle sprinklers. Therefore, inceasing the water application reduced the relative spray losses.

The effect of distance from sprinkler on evaporation and wind drift losses was determined. The losses increased as the distance from the sprinklers increased (Fig. 2). This increase results from the greater distance the water droplets must travel through the air from nozzle to catch cans. These results, however were obtained with a single nozzle sprinkler and do not necessarily represent conditions in the middle of a sprinkled filed. The curves in Fig. 2 show that operating pressure has less effect on evaporation and drift losses, whereas nozzle size and climatic parameters have more effect on it.

The spray losses occuring under field conditions were investigated. The average loss decreased and the results are given in Table 2 for both the two sprinklers, and the permanent sprinkler system. The evaporation and drift loss percentage increased as the distance increased towards the edge of the sprinkled area. This is a normal edge effect for irrigated area in arid and semi-arid areas. Therefore, the losses could be reduced by overlapping system.

The results obtained from the single nozzle sprinklers were utilized to develop an empirical model relating evaporation losses as a function of the different evaporation controlling variables. The five independent variables that were considered to influence sprinkler evaporation losses were nozzle size (d), wind velocity (V), air temperature (T), operating pressure (P) and relative humidity (RH).

Regression analysis of the data obtained were performed using stepwise regression, forward selection, backward selection and General Linear model techniques with the five variables. All the techniques gave about the same type of results. The resulting models were as follows:

1- One variable 'best' model:

$$E = 108.47 - 14.74\, d$$

$$(R^2 = 0.90,\ cv = 12.43\%)$$

Table 1. Average evaporation losses from a single sprinkler under various climatic and operating conditions.

No. of observation	Nozzle diameter (mm)	Wind velocity (m/s)	Air temperature (C)	Operating pressure (kPa)	Relative humidity (%)	Evaporation loss (%)
1	2.29	3.07	36.73	200	45.17	75.70
2		3.30	35.15	250	43.00	74.63
3		2.76	33.39	300	48.67	67.16
4	2.77	2.94	35.86	200	49.00	64.63
5		2.97	35.55	250	41.83	65.51
6		2.70	35.52	300	45.67	63.78
7	3.57	3.06	38.40	200	50.50	63.43
8		2.40	36.68	250	51.17	61.13
9		2.03	34.09	300	53.60	58.46
10	3.68	2.98	37.60	200	42.50	56.53
11		2.82	35.22	250	45.17	53.33
12		2.92	32.27	300	45.33	51.12
13	3.97	3.01	36.88	200	47.50	54.44
14		1.82	36.62	250	48.50	57.66
15		1.64	34.78	300	45.67	49.59
16	4.57	2.97	38.49	200	46.50	53.10
17		2.79	36.66	250	45.17	51.86
18		2.08	33.93	300	47.50	48.54
19	4.76	2.32	38.48	200	38.50	38.98
20		2.18	35.39	250	39.67	37.99
21		1.57	32.67	300	36.33	35.27
22	5	4.60	37.09	200	45.83	42.78
23		4.21	35.97	250	43.50	43.18
24		3.49	34.25	300	50.33	37.94
25	6.1×3	3.61	34.00	200	56.70	22.60
26		3.21	41.50	250	45.00	34.00
27		3.65	42.00	300	49.00	33.20
28	5.5×4.2	2.84	35.60	200	42.00	25.60
29		2.35	36.50	250	46.00	29.00
30		2.33	36.00	300	44.00	30.80

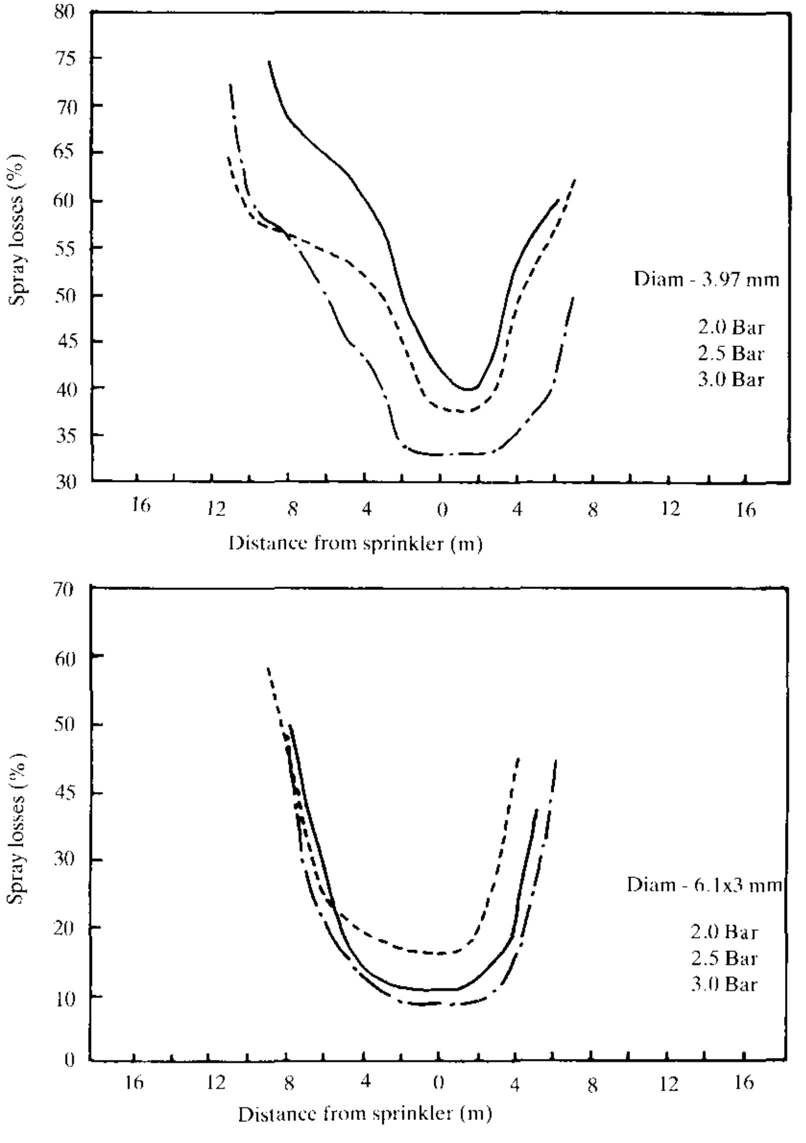

Fig. 2. Variation of spray losses with distance from a single sprinkler at different operating pressures.

Table 2. Average evaporation losses from overlapping of sprinklers under field conditions.

No. of sprinkler*	Nozzle diameter (mm)	Wind velocity (m/s)	Air temperature (C)	Operating pressure (kPa)	Relative humidity (%)	Evaporation loss (%)
2	2.29	2.30	25.00	200	41.00	60.50
		1.50	28.00	250	40.20	63.30
		1.50	22.00	300	43.00	55.00
2	3.97	3.80	38.00	200	38.00	45.20
		3.20	37.00	250	39.00	42.00
		2.80	35.00	300	39.00	40.00
9	2.77	2.20	30.00	200	39.80	24.60
		1.80	30.00	250	41.20	22.70
		1.80	28.00	300	43.00	19.60

* The number of sprinklers overlapped during the test

2- Two variable 'best' model:

$$E = 69.50 - 13.96\,d - 0.79\,RH$$
$$(R^2 = 0.93,\ cv = 11.05\%)$$

3- Three variable 'best' model:

$$E = 17.71 - 14.30\,d - 0.76\,RH + 1.52\,T$$
$$(R^2 = 0.95,\ Cv = 9.96\%)$$

4- Four variable 'best' model:

$$E = 13.66 - 14.27\,d - 0.79\,RH + 1.73\,T - 1.79\,V$$
$$(R^2 = 0.95,\ Cv = 9.88\%)$$

5- Five variable 'best' model:

$$E = 10.86 - 14.29\,d - 0.79\,RH + 1.79\,T - 1.75\,V + 0.0031\,P$$
$$(R^2 = 0.95,\ Cv = 10.15)$$

where:

E = evaporation and drift losses
R = correlation coefficient
cv = coefficient of variation

The results of the regression analysis indicate that the nozzle size and relative humidity are the predominant factors affecting the spray loss from the sprinkler nozzles. The operating pressure had very little effect on the evaporation losses, for the pressure heads used in this study. This order suggests that the losses from the sprinklers could be minimized if it is operated with large nozzle size and under calm and mild hours of the day. The four variable model also showed that the losses increased with decreasing nozzle size and relative humidity and increased with increasing air temperature and wind velocity. Similar observations were reported by Frost and Schwalen [1], Clark and Finley [11], Ali and Barefoot [7] Yazar [8], and others. The nozzle size was included in this study because many models for the prediction of evaporation and drift losses during sprinkling reported in the literature are lacking this variable.

Conclusions

A study was conducted in which water losses during sprinkling were determined for various climatic and operation conditions. The results show that evaporation and wind drift losses are dependent upon both climatic parameters and operating conditions. The losses increased with decreasing nozzle size and relative humidity, and increased with increasing air temperature and wind velocity. Also, the results showed an increase in spray losses with an increase in distance from the sprinkler. The study also showed that the losses could be reduced if the sprinklers are overlapped.

The evaporation and drift loss model indicated that the five independent variables considered all the affected losses. In descending order or importance they were nozzle size, relative humidity, air temperature, wind velocity and sprinkler operating pressure.

The study is expected to draw the attention of sprinkler irrigation system designers and farmers to the importance of selecting the proper nozzle and the time of irrigation. The climatic parameters should be considered adequately when evaluating the design of the sprinkler systems. This will lead to the saving of precious resource in areas of limited water supply, and under hot and arid conditions.

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فواقد التبخر وبعثرة الرياح من نظام الري بالرش تحت ظروف حارة وجافة

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ملخص البحث. تم تقدير فواقد التبخر وبعثرة الرياح من الرشاشات تحت مجموعة من الظروف المناخية والتشغيلية المختلفة. ودلت نتائج هذه الدراسة أن هذه الفواقد تتغير عكسيًّا مع قطر فوهة الرشاش والرطوبة النسبية وتناسبيًّا مع درجة حرارة الهواء وسرعة الرياح وكذلك ضغط تشغيل الرشاش، وقد تم استنتاج نموذج لتقدير فواقد التبخر، وأشارت نتائج هذا النموذج إلى أن هذه الفواقد الناتجة من نظام الري بالرش تتعلق مباشرة بالعوامل الثلاثة التالية أكثر من غيرها وهي على الترتيب:

قطر فوهة الرشاش المستخدم، ثم الرطوبة النسبية، ثم درجة حرارة الهواء.