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The Effect of Riser Height and Nozzle Size on Evaporation and Drift Losses under Arid Conditions

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Abstract. Quantitative determination of evaporation and drift losses from impact sprinklers were carried out under various operating and climatic conditions. The results show that the losses increased with increase in riser height and wind speed and decreased with increase in nozzle size and relative humidity. Also, the results demonstrate the effects of riser height and nozzle size on the water distribution patterns.

The evaporation and drift losses model indicated that spray losses from sprinklers are most directly related to the riser height, nozzle size and wind speed, in descending order.

Introduction

With population growth in the world, the demand for water is increasing. Hence the necessity for conservation of water resources increases, particularly in countries of limited water supply, where the agricultural irrigation has traditionally been the major water use sector in these areas, usually in the range of 80-90% [1,pp217-238)]. Thus the water application efficiency is becoming increasingly important as energy, water costs rise, and water conservation are emphasized. This increases the need for better designed and managed sprinkler irrigation systems.

The application efficiency of sprinkler irrigation system can be significantly influenced by the amount of evaporation and wind drift losses [2,3]. In most sprinkler irrigation systems, part of the water leaving the nozzle evaporates before it reaches the soil surface or the crop canopy, thereby reducing the efficiency of sprinkler irrigation. Evaporation not only reduces the depth of water reaching the ground but also increases the salinity of the remaining water [4]. The evaporation and wind drift losses are highest when sprinklers that produce large quantities of small droplets are operated in hot, dry, windy conditions [4,5], and when irrigation water is warm [6,7]. These losses in desert areas may amount to a high portion of the total water applied.

Sprinkler irrigation evaporation and wind drift losses have been the subject of numerous field, laboratory and analytical studies. A wide range of losses have been reported in the literature due to the many design, climatic and operation parameters involved. Several investigators have studied the effect of these parameters on evaporation and wind drift losses. These losses are taken as the difference between the amount of water leaving the nozzle and that measured with a grid network of catch cans. Frost and Schwalen [8] 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. Strong [9] found that evaporation and wind drift losses increased as the riser height of sprinkler increased. However, Wiersma [10] reported opposite results. Kraus [11] found that evaporation and wind drift losses ranged from 3.4 to 17%, and 36% of these losses was due to wind drift. Sternberg [12] reported that wind drift losses were 60% of the total losses. Hermsmeier [4] found that evaporation and wind drift losses can range from 0 to 50%, and these losses are more closely related to air temperature and application rate than to wind velocity or relative humidity, while Seginer and Kostrinskly [13] concluded that evaporation loss was negligible relative to drift loss. Ali and Barefoot [14] measured evaporated losses of 45-48% and concluded that relative humidity and air temperature were the most significant parameters influencing the evaporation losses. Kohl *et al.* [15] reported that evaporation and drift losses ranged from 0.4 to 1.4% and that small droplets are more susceptible to evaporation and wind drift which is also reported by Thompson *et al.* [16]. Representatives of the sprinkler irrigation industry indicate that 10 to 25% of the water leaving the nozzle is lost between the sprinkler nozzle and the crop canopy [15].

There are differences between the reported results and even differences of the effects of climatic parameters (e.g. wind velocity, relative humidity) and design parameters (e.g. riser height) upon evaporation losses.

Losses from sprinkler irrigation in arid and desert areas may amount to a considerable portion of the water discharged by the sprinklers. The magnitude of these losses depends upon the climatic and operating conditions. To obtain an insight into the magnitude of these losses, it is necessary to determine the factors affecting them under local conditions, and hence the relationship can be established. This will help the sprinkler designer and irrigation manager to find ways to reduce evaporation and drift losses during irrigation to conserve water in these arid areas. There is very little information available on evaporation and wind drift losses in hot, dry conditions at different operating conditions such as nozzle height. The objective of this study is to study the effect of nozzle height and size on evaporation and wind drift losses under hot and dry conditions, that conducted under different operating conditions in order to determine relationship between the losses and the factors affecting them.

Materials and Methods

The field studies described in this paper were carried out at the Educational Farm of the College of Agriculture, King Saud University, Riyadh, during the period of July through November, 1992. The evaluation tests were conducted in accordance with ASAE Standards [17, pp. 487-489].

A series of tests were made using a single stationary sprinkler system to determine the evaporation and wind drift losses and the effect of nozzle height and size on the quantity of these losses.

Seven commercial single and double impact sprinklers of different nozzle sizes that are commonly used for field irrigation were selected for this study, as shown in Table 1. Each sprinkler was mounted on 0.5, 1.0 and 1.5 m risers respectively above the ground surface. Three sprinklers from each size were used for each test. Each sprinkler was then operated at the recommended operating pressure. Catch cans of cylinderical 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. Two different nozzle sizes were operated at the same time.

Flow rate, wind velocity, air temperature, and relative humidity were continuously recorded during each test. Sprinklers were operated for a duration of 1 to 2 hours for each run, depending on the nozzle size to collect a sufficient amount of water in the catch cans. The evaporation and wind drift losses were calculated by:

$$E = [\,(d1 - d2) / d1] \times 100$$

in which E = sprinkler evaporation and wind drift losses [%]; d1 = gross water depth applied by sprinkler (mm), d2 = water depth reaching catch cans (mm).

The catch can depths measured from each test were first adjusted for evaporation loss from the cans during measurements. For this purpose, additional three catch cans were used with a premeasured amount of water during the preceding test. These cans were placed outside the vicinity of the sprinkler spray. Depths in these cans were recorded at the end of reading all the cans in the test. The loss in the three

Table 1. Average evaporation and wind drift losses from impact sprinklers under various climatic and operating condition

Nozzle No.	Nozzle Size (mm)	Riser height (m)	Wind speed (km/hr)	Temp. (c)	Relative humidity (%)	Cu (%)	Evaporation and drift losses (%)
A	2.5	0.5	12.6	28.5	13.73	29.4	57.22
		1	13.95	28.5	15.88	34.3	68.31
		1.5	11.25	25.5	17.23	29.77	79.2
B	3.97	0.5	12.61	17	55.5	32	30.38
		1	12.81	27	38.5	31.19	51.93
		1.5	11.38	26.5	51.5	48	74.3
C	4.76	0.5	9.97	37	30	63.75	26.75
		1	7.13	37	31	44.92	44.25
		1.5	5.83	35.5	30.8	27.04	61.41
D	5	0.5	9.47	35.5	28.25	37.53	21.22
		1	5.83	35.5	30.75	32.24	30.64
		1.5	10.43	36.5	30	62.63	52.78
E	4.37 × 2.38	0.5	12.61	17	55.5	37.69	23.6
		1	12.81	27	38.5	50.35	38.56
		1.5	11.38	26.5	51.5	50.7	47.28
F	4.76 × 3.97	0.5	12.6	28.5	13.73	50.71	18.43
		1	13.95	28.5	15.88	35.96	34.42
		1.5	11.25	25.5	17.23	38.59	42.75
G	8.5 × 5.5	0.5	5.83	35.5	30.75	58.05	15.92
		1	6.74	37	30	45.86	28.9
		1.5	9.47	35.5	28.25	55.67	36.42

catch cans was added to the test cans to compensate for losses occurring during measurements. The adjusted catch cans were used to determine the evaporation and wind drift losses and also the sprinkler pattern shape at each height.

Results and Discussion

A series of tests were made with a single nozzle or double nozzle sprinklers under field conditions to determine the effect of riser height and nozzle size on evaporation and wind drift losses and on water distribution for the tested sprinklers.

The water distribution patterns for the various nozzle sizes used in the study are shown in Fig. 1, also the coefficient of uniformity (Cu) for each sprinkler was calculated as shown in the Table. Each sprinkler was operated within the recommended

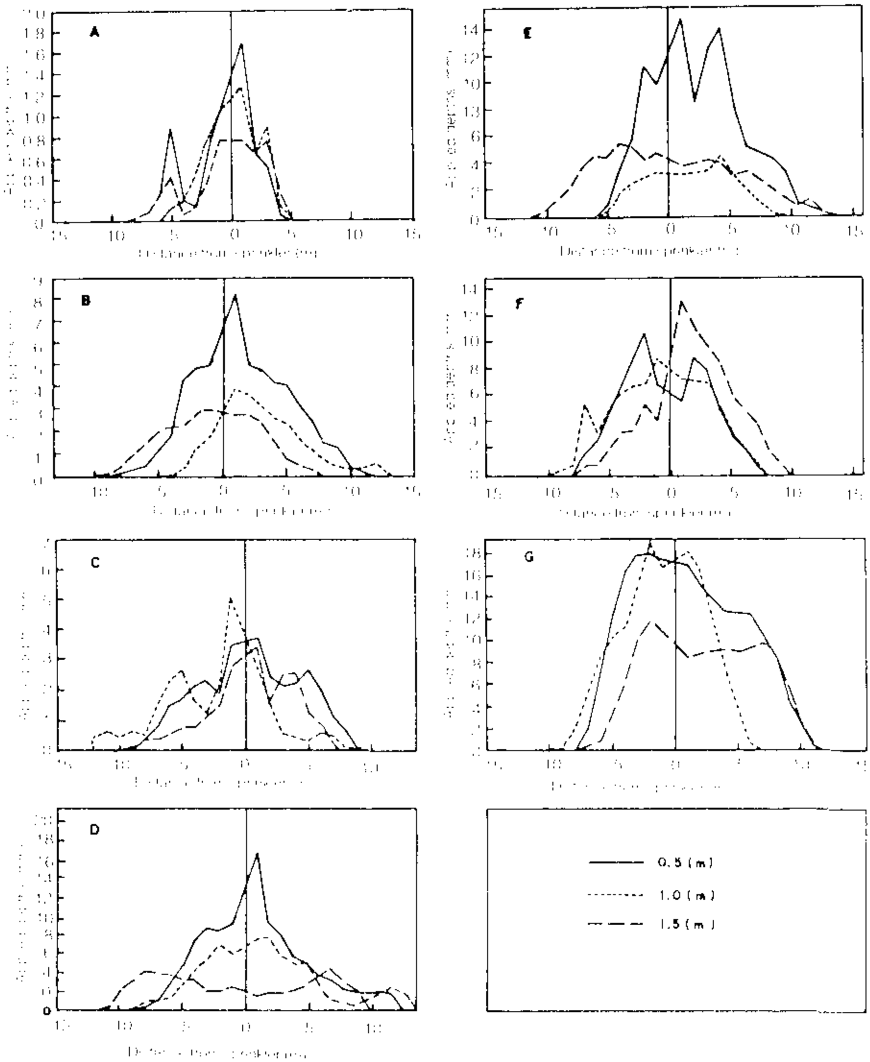

Fig. 1. Sprinkler distribution patterns at different nozzle heights.

operating pressure range. However, the distribution patterns (Fig. 1) beneath the various tested sprinklers showed a variation in water distribution. This variation increases as the riser height increases. This may be due to the effect of climatic factors, particularly the wind speed and direction. But in general, the water was distributed on both sides of sprinkler more uniformly as the rise height decreased or the nozzle size increased (Fig. 1). This may indicate that nozzles with high risers and small sizer are susceptible to climatic factors effects.

The average results of climatic, and operation parameters and their effects on evaporation and wind drift losses are presented in the Table. The average losses ranged from 79.2% for 2.5 mm nozzle size at height 1.5 m to 15.92% for double nozzle (8.5 × 5.5 mm) at 0.5 m riser height. The evaporation and wind drift losses from the tested sprinklers varied widely. This may be due to the changes in climatic and operation factors during the tests.

The effect of riser height on evaporation and drift losses from a single and double nozzles are shown in Fig. 2. It can be seen that the losses increased with increasing the riser height for all nozzle sizes, but there is an increase in the evaporation and drift losses with the decrease in the nozzle size, particularly when the riser height is increased to 1.5 m.

The evaporation and drift losses from different nozzle sizes were determined and shown in Fig. 3. This figure indicates the influence of nozzle sizes (single or double) on these losses at different riser heights. The losses increased with small nozzles and decreased with large nozzle sizes (Fig. 3). This may be due to the fact that small nozzles produce large quantities of small droplets which are susceptible to hot, dry and windy conditions.

The results obtained from the tested sprinklers were utilized to develop an empirical model under hot and dry conditions to relate evaporation and wind drift losses as a function of the different evaporation controlling variables. The most five independent variables that were considered to influence sprinkler evaporation and wind drift losses were riser height, nozzle size, wind velocity, air temperature and relative humidity.

The sprinkler operating pressure was reported to have very little effect on the losses [4,18]. Multiple regression analysis of the data were performed by using stepwise regression, forward selection , backward selection and general linear model techniques with five variables. The adequacy of the models were judged using the criteria suggested by Drapper and Smith [19, pp.130-265]. The criteria of a better fit are (a) the square of the multiple correlation coefficient (R^2) should be higher, (b) the standard error of regression (s) should be smaller, and (c) the coefficient of variation (Cv) should be smaller. The best models for predicting the evaporation and drift losses from impact sprinklers are shown below:

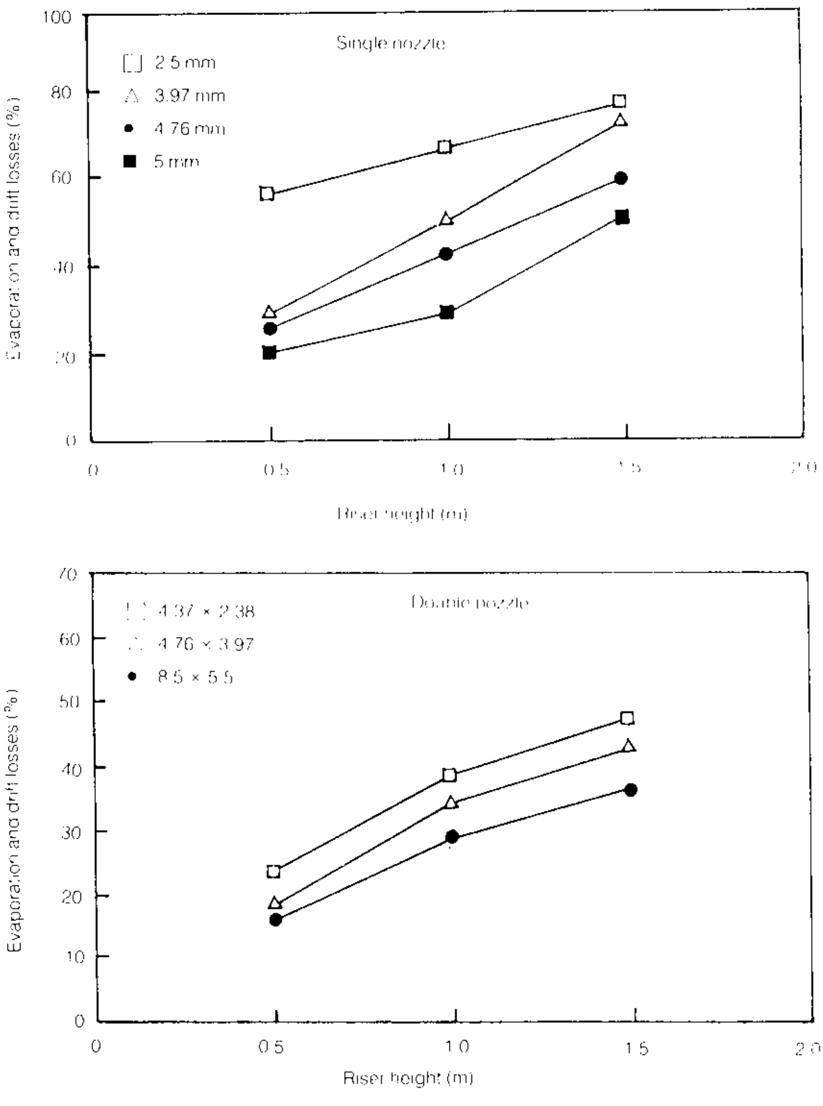

Fig. 2. Relationship between the evaporation and drift losses and riser height with different nozzle sizes.

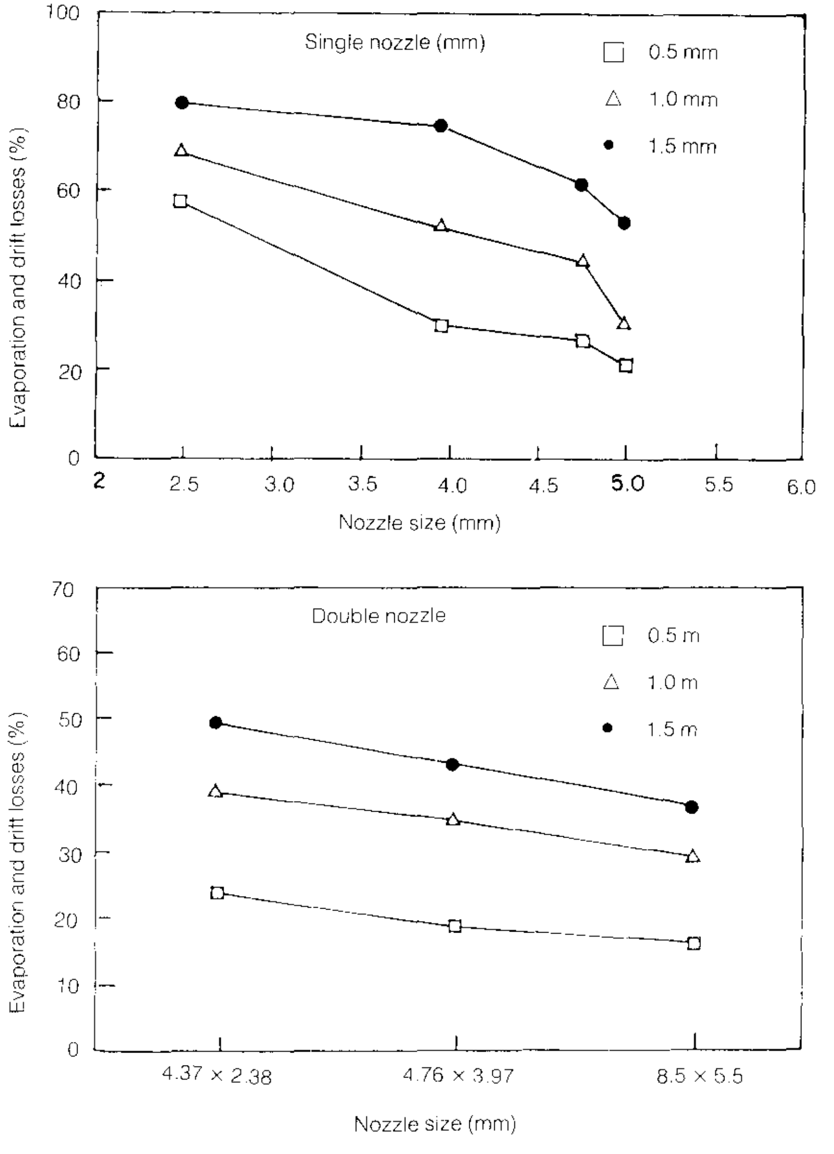

Fig. 3. Relationship between the evaporation and drift losses and nozzle sizes at different riser heights.

$$\ln E = 4.506 - 0.518 \ln D + 0.703 \ln H + 0.137 \ln V - 0.04 \ln RH + 0.022 \ln T \quad \ldots. (1)$$

$$(R^2 = 0.914, \quad s = 0.156, \quad Cv = 4.27\%)$$

where E is the evaporation and drift losses as the percentage of the total depth applied by sprinkler; D is the nozzle diameter (mm); H is the riser height above the ground surface (m), V is the wind velocity (km/hr); RH is the relative humidity (%); and T is the air temperature (C).

When the air temperature variable is eliminated since it had the least effect, then the prediction equation becomes:

$$\ln E = 4.393 - 0.519 \ln D + 0.701 \ln H + 0.148 \ln V - 0.036 \ln RH \quad \ldots. (2)$$

$$(R^2 = 0.912, \quad s = 0.151, \quad Cv = 4.14\%)$$

Since the air temperature term is indirectly included in the relative humidity term, the R^2 value remains approximately unchanged.

When the relative humidity variable is omitted the equation becomes:

$$\ln E = 4.260 - 0.521 \ln D + 0.701 \ln H + 0.155 \ln V \quad \ldots. (3)$$

$$(R^2 = 0.912, \quad s = 0.147, \quad Cv = 4.04\%)$$

Eliminating the wind velocity and considering only the relationship between the evaporation and drift losses, the nozzle diameter, and the riser height; the resulting equation becomes:

$$\ln E = 4.668 - 0.55 \ln D + 0.692 \ln H \quad \ldots. (4)$$

$$(R^2 = 0.902, \quad s = 0.15, \quad Cv = 4.12\%)$$

The correlation between the sprinkler evaporation and wind drift losses and either nozzle diameter or riser height alone was poor ($R^2 < 0.42$).

The results of the regression analysis of the data indicate that the riser height and nozzle diameter are the predominant factors affecting the evaporation and wind drift losses from sprinkler sprays. Also, the results show that air temperature, relative humidity are of less importance for estimating such losses.

Figures 2 and 3 show the effect of the riser height and nozzle size on the sprinkler losses. Figure 2 shows that the evaporation and drift losses increase with increasing the riser heights and decrease with increasing nozzle sizes as indicated in Fig. 3. This study suggests that the losses from the sprinklers could be minimized if it is operated with large nozzle and at lower riser heights, particularly in areas with limited resources of water and under hot and dry conditions.

Conclusions

This study was conducted to determine the evaporation and with drift losses during sprinkling under various climatic and operation conditions. The losses are dependent upon both climatic and operating factors, and ranged for the tested sprinklers from 15.92 to 79.2%.

The evaporation and drift losses model indicated that the following five independent variables affected the evaporation and drift losses in descending order, which are: riser height, nozzle size, wind velocity, relative humidity, and air temperature. The riser and nozzle size were the predominant factors affecting the evaporation and wind drift losses.

The results show that double nozzle sprinklers gave the more uniform distribution patterns and less evaporation and drift losses. These sprinklers are more suitable to the arid conditions, in terms of saving water and increase the sprinkler irrigation system efficiency.

The study is expected to draw the attention of sprinkler irrigation system designers and users to the importance of selecting the proper riser height and nozzle size. Also, the climatic factors should be considered during design and evaluation of the system. This will lead to save energy and conserve water in areas of limited water supply.

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تأثير ارتفاع حامل وحجم الرشاش على فواقد التبخر وبعثرة الرياح تحت الظروف الجافة

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ملخص البحث. أجريت دراسة لتقدير كميات فواقد التبخر وبعثرة الرياح من رشاشات دوارة تحت ظروف تشغيلية ومناخية متنوعة.

وقد أوضحت نتائج الدراسة زيادة هذه الفواقد مع زيادة ارتفاع حامل الرشاش وسرعة الرياح وتقل مع زيادة قطر فوهة الرشاش والرطوبة النسبية. كذلك أوضحت تأثير كل من ارتفاع حامل وحجم الرشاش على توزيع المياه من هذه الرشاشات.

وقد أظهر نموذج التبخر وبعثرة الرياح على أن هذه الفواقد تتأثر بدرجة كبيرة بالعوامل التالية أكثر من غيرها وهي بالترتيب ارتفاع حامل الرشاش، حجم فوهة الرشاش وسرعة الرياح.