

# Spray evaporation losses from sprinkler irrigation systems

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McLean, R.K., Sri Ranjan, R. and Klassen, G. 2000. **Spray evaporation losses from sprinkler irrigation systems**. Can. Agric. Engr. 42:001-008. Minimising the loss of water from irrigation systems is important for achieving water and energy conservation. Water is lost during storage, conveyance and field application. In sprinkler irrigation systems, the loss that occurs in the field is the largest of the three. The above canopy spray evaporation loss (ACSEL) represents the portion of the water that is lost to the atmosphere during the time it travels from the sprinkler nozzle to the crop canopy. The electrical conductivity (EC) method was used to determine the ACSEL from different types of sprinkler irrigation systems calculated at increasing distances from the sprinkler nozzles. In this method, the change in solute concentration and consequent change in EC as the water droplets travel through the air was used to calculate the volume lost by evaporation. The travelling gun irrigation systems showed the largest variation in ACSEL. The ACSEL varied depending on whether the water droplets travelled into the wind or with the wind. Therefore, for measuring ACSEL, it is important to place the collectors on either side of the travelling gun. The wind direction in relation to the average travel direction of the gun also affected the uniformity of ACSEL. The centre pivot irrigation systems gave the most uniform ACSEL across the different nozzles. Therefore, for centre pivot systems, about four to six collectors per row is sufficient to determine ACSEL in the field with a precision of  $\pm 0.5\%$ .

Afin d'améliorer la conservation de l'eau et de l'énergie en irrigation, il est important de minimiser les pertes d'eau des systèmes. L'eau est perdue lors de l'entreposage, du transport et de l'application au champ. Pour les systèmes d'irrigation par aspersion, la perte d'eau au champ est la plus importante des trois. La perte d'eau par évaporation au-dessus du feuillage (ACSEL) représente la partie de l'eau qui est perdue dans l'atmosphère au moment où elle passe de la buse au feuillage. La méthode de la conductivité électrique (EC) fut utilisée pour déterminer l'ACSEL de différents types de systèmes d'irrigation par aspersion, à des distances croissantes des buses. Le volume d'eau perdu par évaporation fut calculé grâce à la mesure du changement de concentration de la solution, et donc du changement de conductivité électrique (EC), des gouttes qui se déplacent dans l'air. Les plus grandes variations d'ACSEL furent observées avec des systèmes d'irrigation à canon mobile. L'ACSEL variait selon que les gouttes se déplaçaient avec ou contre le vent. Il est donc important, lorsqu'on mesure l'ACSEL, de placer les récipients collecteurs de chaque côté du canon mobile. La direction du vent par rapport à la direction moyenne de déplacement du canon eut également un effet sur l'uniformité de l'ACSEL. Les valeurs d'ACSEL de systèmes d'irrigation à pivot central furent les plus uniformes. Quatre à six récipients collecteurs par rangée sont donc suffisants pour déterminer l'ACSEL d'un système d'irrigation à pivot central à une précision de  $\pm 0.5\%$ .

## INTRODUCTION

Interest in water conservation is increasing as a result of ever increasing demands on scarce water resources. Properly designed irrigation systems can minimize the losses of the water delivered to the plants. Among the different systems used for irrigation, the sprinkler irrigation system is one of the popular methods for achieving high application efficiencies. In Manitoba, most of the field crop irrigation is done by sprinkler irrigation systems consisting of travelling guns, side-roll systems, linear move systems, or centre pivot systems. In a sprinkler irrigation system, very little water is lost in the conveyance system up to the sprinkler nozzle. Therefore, most of the losses are expected to take place from the moment the water leaves the nozzle until it reaches the soil within the root zone (Seginer 1966; Clark and Finley 1975; Steiner et al. 1983; Kincaid and Busch 1986).

The various components of the losses in irrigation systems need to be identified before any improvements on the design of irrigation systems can be made. As mentioned previously, the losses that occur up to the sprinkler nozzle are relatively minimal and are preventable. Once the water leaves the sprinkler nozzle, it travels through the air and reaches the crop canopy or the soil surface. The portion of the water that is lost by evaporation during the time it travels through the air and before it reaches the crop canopy is called "above canopy spray evaporation losses" (ACSEL). Another portion is intercepted by the crop canopy and part of this is evaporated back to the atmosphere. Any drift losses that occur as a result of the wind are not considered a loss as long as the spray drift falls within the boundaries of the cultivated area. The drift component only affects the uniformity of water application. However, if the drift component leads to local over application of water which results in deep percolation below the root zone, it should be taken into account in calculating the overall farm irrigation efficiency. The water application efficiency is defined as the water beneficially stored in the plant root zone as a percent of the total amount of water delivered to the field. In sprinkler irrigation systems that are well-maintained, a major portion of the loss in the field occurs from the time water leaves the sprinkler nozzle until it reaches the root zone. Losses at the field level include evaporation from spray droplets that are travelling through the air (ACSEL), the portion intercepted by the crop canopy, and water deep percolating below the root zone.

The ACSEL does not include the portion of the water that is intercepted by the crop canopy. In a sprinkler irrigation system, ACSEL comprises a major component of the total losses occurring between the sprinkler nozzle and the plant root zone. This study was initiated by the Association of Irrigators in Manitoba to measure the ACSEL in southern Manitoba. The results from this study will help producers understand how much of the irrigation water is lost by spray evaporation under conditions prevailing in Manitoba.

There are many factors that contribute to spray evaporation losses including weather variables and types of equipment. This study follows two phases. In Phase 1, the equipment-related factors were identified in preparation for Phase 2. In Phase 2, the impact of weather-variables and other factors will be studied. The results from Phase I which determine equipment-related factors that influence spray evaporation losses are presented herein. The results show the ACSEL as a function of relative distance from the sprinkler nozzle.

The Phase 2 study to identify the impact of different weather variables will be repeated under different weather conditions. One of the assumptions is that the weather variables do not change during the period of testing which lasted about an hour. In Phase 1, the number of water samples collected per test ranged between 40 and 60. The smaller the number of water samples which must be collected, the shorter the duration of each weather-condition test. Therefore, any reduction in the number of samples that are still representative of typical losses from the nozzles, as determined in Phase 1, will be useful in the Phase 2 experiments that investigate weather variables. Phase 1 results will also help determine the number and proper placement of collectors for sampling water from different types of irrigation systems.

For the purpose of this study, the above canopy spray evaporation losses (ACSEL) were defined as the amount of water that evaporates while the water droplets travel between the spray nozzle and the crop canopy, calculated as a percentage of water that leaves the nozzle. Traditionally, the losses are determined from volumetric or gravimetric measurements of water collected in catch-cans (Frost and Schwalen 1955; Kincaid and Busch 1986). An inherent drawback in these volume-based, catch-can studies is that the spray evaporation losses are included with the wind drift losses. For the same nozzle height, droplet size, and exit pressure, wind drift losses are affected only by the wind speed and direction, while the spray evaporation losses are affected by both wind speed and other weather variables such as ambient temperature, vapour pressure deficit, relative humidity, etc. Since this project measured the ACSEL only, it was desirable to separate the wind drift loss component from the spray evaporation loss component. George (1955) used the electrical conductivity (EC) method to measure only the ACSEL component.

The electrical conductivity method is based on the premise that any loss or gain of water by the droplet travelling through the air will lead to a corresponding change in its solute concentration, and hence its electrical conductivity. As a droplet of water travels through the air, it loses water through evaporation. Because the initial solute concentration is usually very low in water used for irrigation, it can reasonably be assumed that there will be no precipitates out of the droplet as it is evaporating. As the water evaporates from the droplets the

solute concentration increases. By measuring the changes in the electrolyte concentration of the water, it is possible to quantify the collective volume of water lost by the droplets as they travel through the air. As the water evaporates, the solute concentration increases, and the electrical conductivity also increases.

By measuring the EC of the source water and the EC of the water caught in individual collectors positioned just above the crop canopy, the spray evaporation loss was calculated using:

$$Loss(\%) = \frac{EC_c - EC_s}{EC_c} 100 \quad (1)$$

where,

$EC_c$  = electrical conductivity of water in the collector, and  
 $EC_s$  = electrical conductivity of the source water.

In similar studies using the electrical conductivity method, Yazar (1984) reported the losses to be between 1.5 and 16.8% of the total sprinkled volume on tests performed in Nebraska. Yazar also found that wind velocity and vapour pressure deficit were the most significant factors affecting the losses.

George (1955) used the EC method to measure the evaporation losses and found maxima near the sprinkler and at the periphery of the application diameter. These results are attributed to the fact that the spray droplets landing closest to the nozzle are the smallest. The droplets travelling to the outside of the grid travel the greatest distance in the air and, therefore, evaporate more.

Frost and Schwalen (1955) found spray losses as high as 45% under extreme conditions of bright sunlight, high temperatures, and low humidity prevailing in Arizona. While these results were obtained from an individual sprinkler, the spray losses on the fringe area of a single sprinkler were not comparable with those occurring under field conditions with overlapping area between sprinklers. Losses were found by subtracting the amount of water arriving at the field surface from the amount of water being applied to the field. Till (1957) measured the spray evaporation losses using the change in concentration of chloride ions in the irrigation water travelling from the sprinkler nozzle to the ground. The results from this experiment were compared with that predicted using Frost and Schwalen's (1955) nomograph and were found to be in close agreement.

Seginer (1966) compared the consumptive use of water from a sprinkler irrigated crop with that from a crop irrigated with a near-the-ground irrigation system. The near-the-ground system was used as a control in which the spray losses and the interception losses were almost completely eliminated. The results indicated a marginally significant ( $p = 0.1$ ) increase in consumption of about 10% for the sprinkler-irrigated crop that was irrigated every three days. However, no significant difference between the treatments was found for the treatments in which the irrigation interval was two weeks.

Using the EC method, Hermsmeier (1973) reported that evaporation from sprinklers could range from 0 to 50% over short periods. Hermsmeier also noted that evaporation during daytime hours is 3 to 4 times the evaporation during nighttime hours during July and August in the Imperial Valley, California. The air temperature and the rate of application were found to be better factors for estimating sprinkler evaporation

than wind speed or relative humidity. Hermsmeir (1973) found that pan evaporation data along with rate of application could provide a good estimate of sprinkler evaporation.

Spurgeon et al. (1983) reported that hot, dry, and windy conditions could cause spray evaporation losses from sprinkler irrigation systems to approach 30% of the water applied. In a volume-based study using rain-gauges conducted in Kansas by Steiner et al. (1983), the average spray loss was found to be about 15% under highly evaporative conditions. They also estimated the seasonal losses of plant-intercepted water to be about 2 to 4%.

There are many equipment-related factors such as droplet size, nozzle angle, and pressure that contribute to spray evaporation losses. Previous studies have shown that water droplet size is an important consideration in the design of sprinkler irrigation systems. Small droplets are more susceptible to wind drift and evaporation. Droplet size can affect both the wind distortion of the spray pattern and spray evaporation losses. Equipment variables that affect the droplet diameter are the nozzle size, geometry, and operating pressure. Kohl and Wright (1974) and Dadiao and Wallender (1985) have shown that the size of the spray droplets was proportional to the nozzle diameter. In addition, many researchers have found that the spray droplet size at any distance from the sprinkler is related to the nozzle size (Dadiao and Wallender 1985; Edling 1985; Hills and Gu 1989). Dadiao and Wallender (1985) also found that the droplet size was a function of nozzle pressure. As the pressure increases, the initial velocity of the droplets increases leading to an increase in the distance travelled by the droplets. Many researchers have reported that the diameter of the nozzle played a major role in the break up of the droplets and indirectly influenced the evaporation losses (Kohl and Wright 1974; Solomon et al. 1985). Frost and Schwalen (1955) found that a 25% increase of nozzle operating pressure increased the evaporation losses by 25%. They also noted that smaller nozzle diameters tended to break up the droplets leading to greater evaporation losses.

Chaya and Hills (1991) reported that for a given nozzle size, the droplet size was found to be inversely proportional to the operating pressure. In addition, the droplet diameter was also found to be proportional to the Reynolds number of the water. They also evaluated the sprayer design and found the fixed-coarse plate sprayers tended to produce more uniform droplet size than other sprayer designs. Spinners that had double jets leaving the orifice, produced smaller droplets compared to spinners with single jets. The droplet formation from jet breakups in microsprayers was found to be similar to that of conventional agricultural sprinklers. Vories and von Bernuth (1986) found that a sprinkler of a given nozzle size, trajectory angle, and operating pressure produced a set range of drop sizes.

Kohl and DeBoer (1984) observed that for low pressure spray type agricultural sprinklers, the geometry of the spray plate surface, rather than the nozzle size and operating pressure, was the dominant variable that influenced drop size distribution. They also found that smooth spray plates produced smaller droplets compared to coarse-grooved spray plates.

Low pressure spray heads used in centre pivot and linear move systems tended to have similar components, which

consisted of a nozzle that released a vertical jet of water onto a spray plate or oscillating-grooved cone rotating in a plane perpendicular to the water jet. The low pressure heads operate at 100 to 175 kPa and the wetted diameter of the throw is about 10 m (compared to 30 m for impact heads). The low-pressure heads had a droplet size ranging from 1 to 3 mm compared to 3 to 6 mm diameter for impact-sprinkler heads (Longley et al. 1983). Low-pressure heads are usually mounted on retractable drop-tubes that bring the nozzles closer to the crop canopy.

Most of the above findings attributed the spray evaporation losses to weather variables and to some extent on the type of equipment used for testing. The applicable weather variables include: wind speed, vapour pressure deficit, air temperature, and solar radiation. Thus, any experiment to investigate the weather variables should ideally be conducted under controlled conditions with the ability to change each weather variable independently. Such an experimental set up is too expensive to implement. An alternative plan is to use irrigation systems under widely varying weather conditions with the hope that many different combinations of weather-variables could be captured over several seasons. This will require a large number of tests during which the weather conditions could reasonably be assumed to be constant during each test. If the electrical conductivity method is to be used for such a study, the number and placement of collectors used in sample collection will determine the time required for each test. In addition, the placement of the collectors should give a representative evaporation loss. In this study, the spray evaporation loss data are presented as a function of distance from the nozzle for different types of irrigation systems. The following questions will be answered by these experiments. Is there a difference in spray evaporation losses from a single sprinkler system depending on where the sample is collected? Does the wind direction in relation to the spray pattern of the irrigation system affect the spray evaporation losses? Answers to these questions will also help plan the optimum placement of collectors for the determination of spray evaporation losses.

## MATERIALS and METHODS

Table I shows a listing of the type of equipment tested in this study. The wind direction in relation to the average travel direction is reported for the travelling guns. The travelling guns throw water much farther compared to other types of systems and, therefore, are prone to wind drift. The actual sample sizes indicate the number of collectors used during each test except for the travelling guns. The samples collected from the extreme ends of the rows were not included in the sample size.

Up to 60 water samples had to be collected at various distances from the sprinkler nozzles. The collectors were cut from the inverted neck portion of two-litre clear plastic bottles (Fig. 1). The height of the container was 150 mm from the base to the top. Sixty catch-container stands were placed in the field in a grid formation. The stands were spaced at various distances depending on the wind velocity. Approximately four source water samples were taken for each test at 15 min intervals. The source water samples were collected directly from the water leaving the nozzles. Some systems had a diverter valve in the irrigation pipe supplying the water which could be used to collect the water sample. A weather station, consisting of a psychrometer, a wind direction indicator, and an anemometer



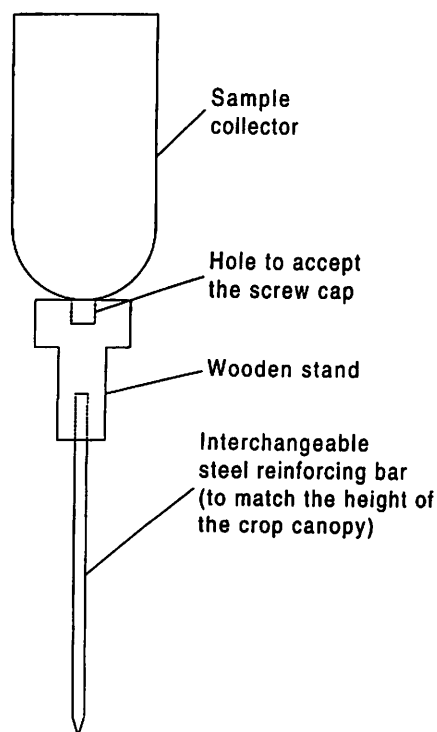
**Table I. Coefficient of variation and required sample sizes for the different tests.**

Type of irrigation equipment		Actual sample size/row	Row 1		Row 2		Row 3		Row 4	
			CV	RSS*	CV	RSS	CV	RSS	CV	RSS
Travelling gun (ABI Irrigation AT110)† (Figs. 2 - 4)	0°	16‡	0.13	8	0.10	4	n/a	n/a	n/a	n/a
	45°	13‡	0.18	25	0.19	28	0.17	23	n/a	n/a
	90°	10‡	0.09	7	0.09	5	0.08	5	n/a	n/a
Lockwood 2265 centre pivot with impact sprinklers (Fig. 5)	Test 1	15	0.31	1	0.22	1	0.90	20	0.20	1
	Test 2	15	0.56	2	0.45	1	0.33	1	0.27	1
	Test 3	15	0.34	5	0.32	5	0.15	2	0.25	2
Valmont 4271 centre pivot with flood jets (Fig. 7)	Test 1	15	0.31	7	0.21	2	0.35	7	0.31	6
	Test 2	15	0.69	3	0.58	4	0.61	3	0.62	4
Zimmatic Type 7 Model 510 centre pivot with flood jets (Fig. 8)	Test 1	15	0.17	3	0.38	10	0.21	5	0.16	3
	Test 2	15	0.12	2	0.16	3	0.22	6	0.29	13
Reinke Electrogator 60 KT centre pivot with two-way impact sprinklers (Fig. 6)		16	0.57	3	0.44	7	0.22	2	0.49	2

\* Required sample size (RSS) is calculated based on  $\alpha = 0.05$  and a tolerable evaporation loss precision of  $\pm 0.5$ .

† Angle between wind direction and average travel direction of the travelling gun

‡ Sample size shown does not include the samples from collectors placed at extreme ends.

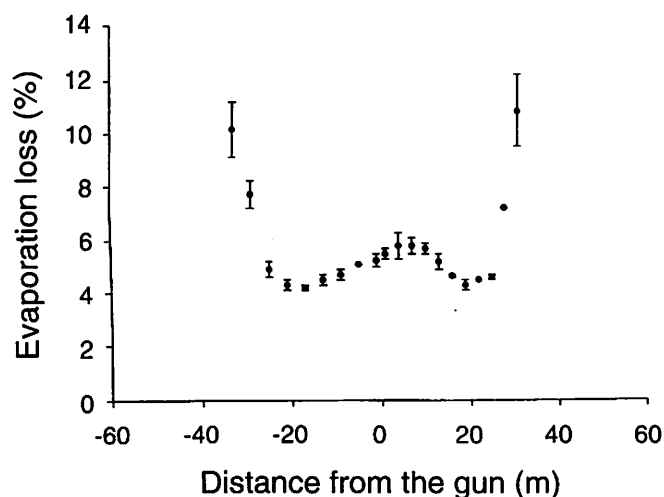


**Fig. 1. Schematic of the spray water sample collector.**

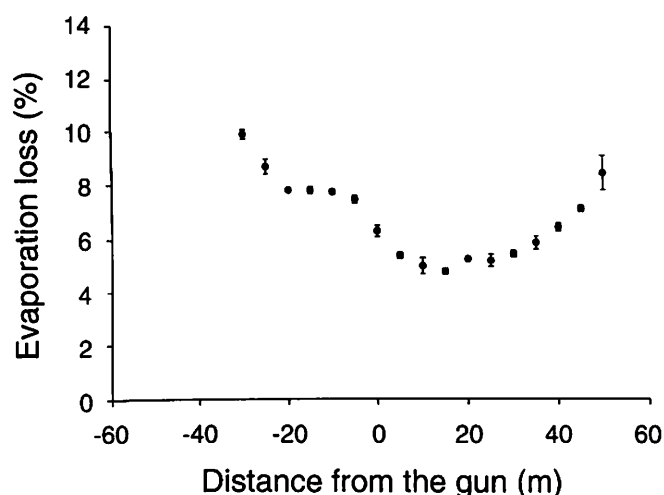
was set up away from the equipment and from any trees or buildings. Weather data were recorded at 15 min intervals.

The collectors were positioned perpendicular to the direction of travel of the sprinkler irrigation system. Once the system passed over the grid, water samples were collected in 60-mL bottles from the collectors taking care to minimize any subsequent evaporation. It took approximately 30 s to collect each water sample. The bottles were rinsed with the collected water once prior to any sample collection. This was done to ensure that any subsequent adsorption of the ions to the interior wall of the sampling bottle would be minimal.

The water samples were placed in the laboratory overnight to equilibrate with the room temperature. Rubber gloves were worn at all times when taking EC readings to prevent contamination of the conductivity cell or the sample bottle. The electrical conductivity was measured for each sample using a YSI Model 32 Conductivity Meter (Yellow Springs Instrument Co. Inc., Yellow Springs, OH). Only 1 mL of a water sample was required for the EC measurement. The meter is capable of reading to  $\mu\text{S}$  with a precision of  $\pm 0.2\%$  full scale. After the electrical conductivity measurements were completed, the collectors were placed in a sink filled with soapy water, washed, and then rinsed with hot water. The washed containers were finally rinsed with distilled-deionized water to remove any remaining solute adsorbed on the walls. The collectors were then hung upside down on drying stands by attaching the caps to elastic bands on the stands. The containers were



**Fig. 2. Travelling gun (ABI Irrigation AT110 Nozzle: Big Gun SR50RN 24° Nelson Irrigation) with wind direction at 0° to the average travel direction.**



**Fig. 3. Travelling gun (ABI Irrigation AT110 Nozzle: Big Gun SR50RN 24° Nelson Irrigation) with wind direction at 45° to the average travel direction.**

allowed to dry overnight and then placed in clean plastic bags for transportation to the field. The sample bottles were also washed with hot soapy water and rinsed with distilled-deionized water. Distilled-deionized water was poured into a few collectors and sample bottles and the electrical conductivity was determined to ensure the sampling equipment was relatively free of any contaminants. If the collectors came in contact with any soil particles, a potential for adding ions to the water samples occurred. Therefore, care was taken to avoid any contamination of the collectors during installation in the field.

The loss of water by evaporation from the collectors during the duration of the sample collection period was considered. Previous research has suggested the use of diesel fuel as an evaporation suppressant in the collectors (O'Reilly and Morrison 1992). However, preliminary experiments done with the addition of the diesel fuel in the collected water caused the electrical conductivity to change as a result of contaminants in

the diesel fuel. Even though the diesel fuel could be used as a suppressant in volume-based studies, it proved to be unsuitable for electrical conductivity-based studies. Therefore, another alternative method had to be developed to account for the evaporation during sample collection. The water samples from the collectors were collected at random within each row of the grid. The time of sample collection was recorded. The electrical conductivities of the samples were plotted as a function of time and any observed trends in the data were analysed. If the spray loss of the sample changed with time, the spray loss as a function of time was plotted and an equation describing the best-fit-line obtained. This equation was used to adjust the measured spray losses based on the time of sample collection. The results presented herein have already been adjusted for any water losses subsequent to collection using the curve-fit equations as discussed above.

The first series of tests were carried out using an ABI Irrigation Model AT110 travelling gun irrigation system with a Big Gun SR50RN 24° nozzle (Nelson Irrigation, Walla Walla, WA). (Trade names are given for identification purposes only.) The grid was arranged such that the entire radius-of-throw of the gun was covered. Thus, the distribution of the losses as a function of distance from the nozzle could be determined. The tests were carried out only when a steady wind in the desirable direction was observed. Since all of the tests were carried out in the field, multiple rows of catch-containers were used to compensate for the inability to reproduce the wind velocities in the desirable orientations for a repeat test. The individual rows served as replicates for each test.

The coefficient of variation (CV) and the minimum sample size (N) was calculated for data from each row of collectors. The minimum sample size (N) was calculated using:

$$N = \frac{t^2 s^2}{E^2} \quad (2)$$

where:

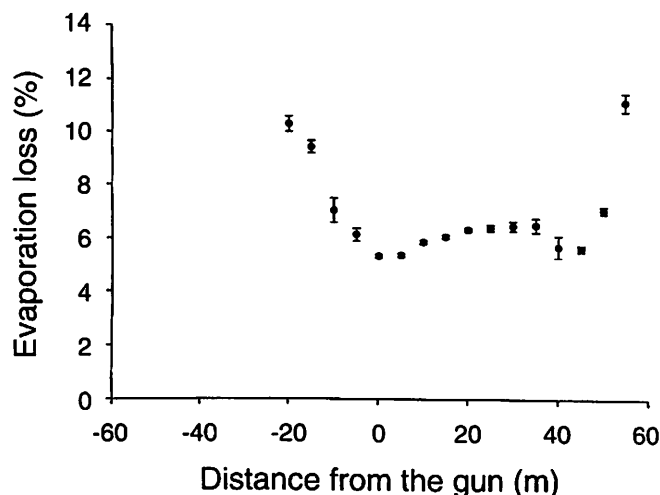
- t = 95% confidence limit for (n-1) degrees of freedom (n = number of samples/row),
- s = sample standard deviation, and
- E = tolerable precision in spray evaporation losses ( $\pm 0.5\%$ ).

The precision of the conductivity meter is  $\pm 0.2\%$  of full scale in the range of electrical conductivities measured with the field samples. A larger tolerable precision for the spray evaporation loss was selected to account for other sources of variation during the test.

## RESULTS and DISCUSSION

Figures 2 through 4 show the spray evaporation losses as a function of distance from the gun. Since the tests were carried out at different times, the weather variables including the wind speed were different for the different tests. Therefore, the losses should not be compared between the different tests and types of equipment.

Results from three different tests shown in Figs. 2 through 4 were carried out for different wind speeds and directions, i.e. wind direction parallel, at a 45° angle, and perpendicular to the average travel direction of the gun. For all the tests, the gun

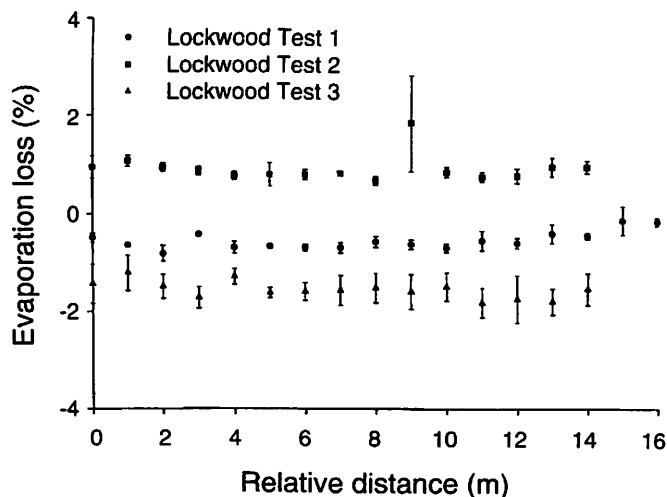


**Fig. 4. Travelling gun (ABI Irrigation AT110 Nozzle: Big Gun SR50RN 24° Nelson Irrigation) with wind direction at 90° to the average travel direction.**

rotated through an angle of 180° or 90° on each side of the line of travel. Thus, the negative distance from the gun refers to the sample collectors that were placed perpendicular to the centre line of gun travel but on the side where the nozzle approaches the line. Positive distances refer to locations on the side where the nozzle retreats from the centre line of gun travel. The error bars represent standard errors calculated using data from the different rows of collectors that were used as replications. Two to three rows of collectors were used as replicates for the tests carried out using the travelling guns. Table I lists the number of samples per row. The weather data was collected at about 15 min intervals to monitor any changes in conditions. Some tests had to be abandoned due to rain or gusty winds during the course of the tests.

Figure 2 shows the results when the wind direction was parallel to the average travel direction of the gun. In this case, the nozzle is throwing the water trajectory with the wind at the mid point. The average losses on either side of the nozzle vary between 4 and 6%, excluding the samples collected beyond 25 m from the nozzle. This is reasonable considering the fact that each side of the grid is exposed to the same environment. The maximum losses (11 to 12%) occurred at the greatest distance from the gun. The water collected beyond 25 m is from the droplets that travelled the greatest distance and, therefore, had the most time to evaporate. The minimum loss (4.3%) occurred at between 15 and 22 m from the gun on either side.

Figure 3 shows the results when the wind direction was 45° to the average travel direction of the gun. The water droplet trajectory is altered by the change in wind direction. On the windward side, the droplets could travel no further than about 30 m from the nozzle. On the other side, the wind seems to carry the droplets as far as 50 m from the nozzle. The evaporation loss on the windward side is about 2% higher than on the opposite side. Since all other weather variables are the same, the difference could be attributed to the difference in wind velocity relative to the droplet velocity. The droplets in the windward side travel across the wind direction, while on the opposite side the droplets travel with the wind. The droplets

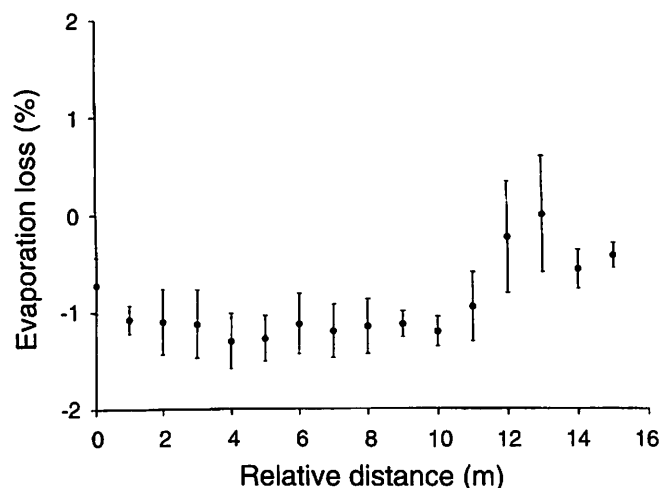


**Fig. 5. Lockwood 2265 centre pivot with impact sprinklers (Nozzle: Senninger 6° 5006) Nozzle location: 4 m above ground at 2.7 m spacing.**

that travel with the wind may experience a lower wind velocity compared to the droplets on the windward side. The characteristic increase towards the end of the trajectory is due to the differences in droplet size. For the travelling gun system, the CV presented in Table I was calculated after excluding data from the extreme ends showing high evaporation losses.

The relative wind velocity effect is even more pronounced in the test carried out when the wind direction was 90° to the average travel direction (Fig. 4). In this case, the water trajectory on the windward side becomes subjected to a higher relative wind velocity compared to the trajectory travelling with the wind direction. Once again, the higher losses towards the ends of the trajectories are due to the differences in the size of the droplets. The loss towards the end on the windward side is mixed with smaller droplets and shows a lower loss relative to the leeward side.

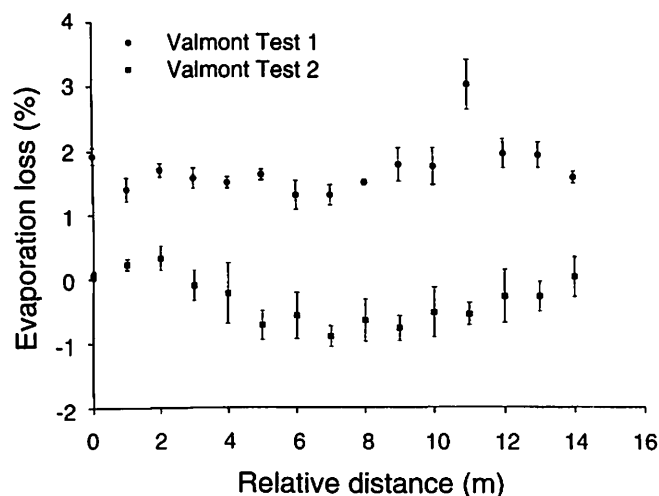
Figure 5 presents data obtained using a Lockwood 2265 Centre Pivot system equipped with Senninger 6° 5006 impact sprinklers located 4 m above the ground at spacings of 2.7 m. Four rows of collectors were used as replicates for the centre pivot systems. Tests 1, 2, and 3 result from three different tests carried out at different times under different weather conditions. Each test was carried out using four rows of collectors as replicates. Collectors were positioned in a direction perpendicular to the direction of travel of the sprinklers. Thus, the rows were placed parallel to the irrigation pipe between the towers towards the middle portion of the pipe. The relative distance shown in Figs. 5 to 8 refers to distance measured along the irrigation pipe with reference to the location of the first set of collectors. Compared to the data from the travelling guns, there is hardly any difference in the average spray losses as a function of distance along each row, indicating that the spray droplets coming from the different impact sprinklers along the pipe were relatively uniform. The CV shown in Table I represents all of the data for the centre pivot system. The negative losses shown for two of the tests were recorded under weather conditions that were conducive to condensation rather than evaporation. Whenever the



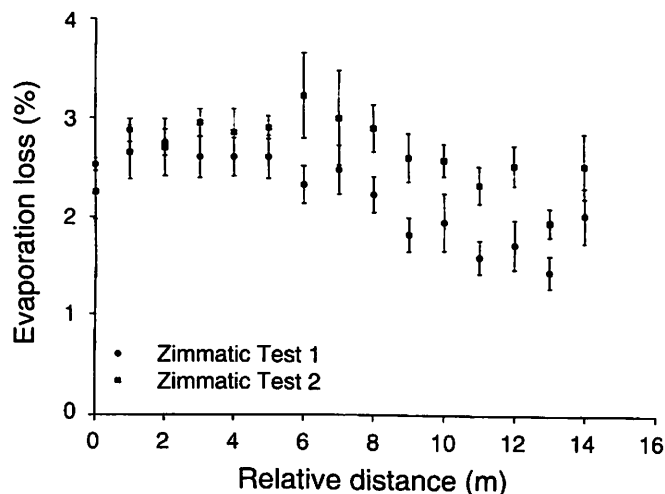
**Fig. 6. Reinke Electrogator 60 KT centre pivot with two-way impact sprinklers (Nozzle: Senninger 6°x6° 5006-2) Nozzle location 4.1 m above ground at 2.9 m spacing.**

temperature of the source water was lower than the dew point temperature of the surrounding atmosphere, water from the air could have condensed on the spray droplets and caused a gain rather than a loss. The groundwater temperature in this area ranged between 7 and 8°C. This was lower than the dew point temperatures recorded during some late evening tests. Table I indicates that about four to six collectors/row are sufficient to measure the losses with a precision of  $\pm 0.5\%$ .

Figure 6 shows the results obtained using a Reinke Electrogator 60KT centre pivot system (Reinke Manufacturing Co. Inc., Deshler, NE) equipped with Senninger 6° x 6° 5006-2 two-way impact sprinklers located 4.1 m above the ground at a spacing of 2.9 m. The gains (negative losses) are fairly uniform across the different collectors. The collector rows were positioned towards the middle portion of the centre pivot pipe. Figure 7 presents data obtained using a Valmont 4271 centre



**Fig. 7. Valmont 4271 centre pivot with flood jets (Nozzle: S.S. Co 3/8 K35) Nozzle location: 3.5 m above ground at 2.9 m spacing.**



**Fig. 8. Zimmatic Type 7 Model 510 centre pivot with flood jets (Nozzle: S.S. Co 1/2 K40) Nozzle location: 4.3 m above ground at 2.5 m spacing.**

pivot irrigation system (Valmont Industries, Omaha, NE) equipped with S.S. Co 3/8 K35 flood jets located 3.5 m above the ground at a spacing of 2.9 m. The losses/gains are uniform across the entire row. The collectors were positioned near the middle portion of the irrigation pipe and the rows were oriented so as to allow the nozzles to pass perpendicular to them. Similar trends were also observed (Fig. 8) in the test carried out using a Zimmatic Type 7, Model 510 centre pivot system (Lindsay Manufacturing Co., Lindsay, NE) equipped with S.S. Co 1/2 K40 flood jets located at 4.3 m above ground at 2.5 m spacing.

## CONCLUSIONS

Based on large numbers of collectors, the ACSELS from the centre pivot systems were found to be uniform for any rotational angle of the pivot. Table I presents the required sample sizes for a tolerable precision of  $\pm 0.5\%$ . Therefore, fewer numbers of collectors/row would likely have been sufficient to measure the spray evaporation losses. The collectors should be positioned towards the mid-span of the irrigation pipe to avoid any edge effects. The sprinklers should completely pass over the collector grid which is oriented such that the nozzles pass over a row of collectors simultaneously. Three to four rows of collectors were used to minimise any variability arising from any change in the weather conditions during the course of data collection. The position of the collectors in relation to the location of the nozzles did not influence the spray evaporation loss measurements, implying that overlap of the spray trajectories from adjacent nozzles is adequate.

The travelling gun data show the distortion of the spray patterns caused by the wind. A difference was observed between the losses on the windward and leeward side. Therefore, it is important to place the collectors on both sides of the travelling gun when measuring ACSEL. The water samples collected towards the end of the throw gave the largest ACSEL. This is not representative of the losses calculated from data using the water samples obtained from the collectors

placed near the gun. The high losses shown in Figs. 2 through 4 towards the end of the throw are likely due to the differences in the size of the droplets. These higher losses occur only over a short distance and can be neglected in estimating average losses for the gun. When the wind direction is parallel to the average travel direction, the losses on either side were found to be almost equal. However, when the wind direction changed, the losses on the windward side were higher than the losses on the leeward side.

In summary, the electrical conductivity method can be used to measure the ACSEL in the field. It is critical to place collectors on either side of the travelling guns so that the effect of the wind can be averaged for spray loss comparisons. For the centre pivot systems, about four to six collectors/row may be sufficient to measure the ACSEL with a precision of  $\pm 0.5\%$ .

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