EVALUATIONS OF THE PERFORMANCE OF TWO TYPES OF SPRINKLER IRRIGATION EMITTERS INSTALLED ON PERMANENT AND DRAGLINE SYSTEMS

GB Simpson • FB Reinders

WRC Report No KV 119/99

Water
Research
Commission

EVALUATIONS OF THE PERFORMANCE OF TWO TYPES OF SPRINKLER IRRIGATION EMITTERS INSTALLED ON PERMANENT AND DRAGLINE SYSTEMS

by

GB Simpson and FB Reinders

of

ARC-Institute for Agricultural Engineering

Project executed on behalf of the
Water Research Commission

May 1999

ARC • LNR
ARC-Institute for Agricultural Engineering
Private Bag X519, SILVERTON, Pretoria, 0127

WRC Report No: KV 119/99
ISBN 1 86845 517 3

EVALUATIONS OF THE PERFORMANCE OF TWO TYPES OF SPRINKLER IRRIGATION EMITTERS INSTALLED ON PERMANENT AND DRAGLINE SYSTEMS

May 1999

CONTENTS

1. EXECUTIVE SUMMARY

South Africa is a water scarce country and the agricultural sector utilises more than 50% of the available water resources in South Africa. The irrigation fraternity is being challenged to manage water demand and implement methods of improving efficiencies. This document reviews evaluations performed on three sprinkler systems as they are utilised in-field to determine their hydraulic performance in terms of applying water to the crop.

The systems evaluated were two impact sprinklers operating on a dragline system and the black pop-up Floppy sprinkler (see photo 1), which was developed in South Africa, on a permanent layout. The individual sprinklers were evaluated on the Sprinkler Test Bench at the ARC-Institute for Agricultural Engineering Irrigation Laboratory, and the sprinklers were evaluated in-field, both at the ARC-Institute for Agricultural Engineering in Silverton and at Transvaal Sugar Limited near Komatipoort. Present sprinkler practices of designers and farmers in the sugar growing regions of Mpumalanga Province were evaluated according to international methods.

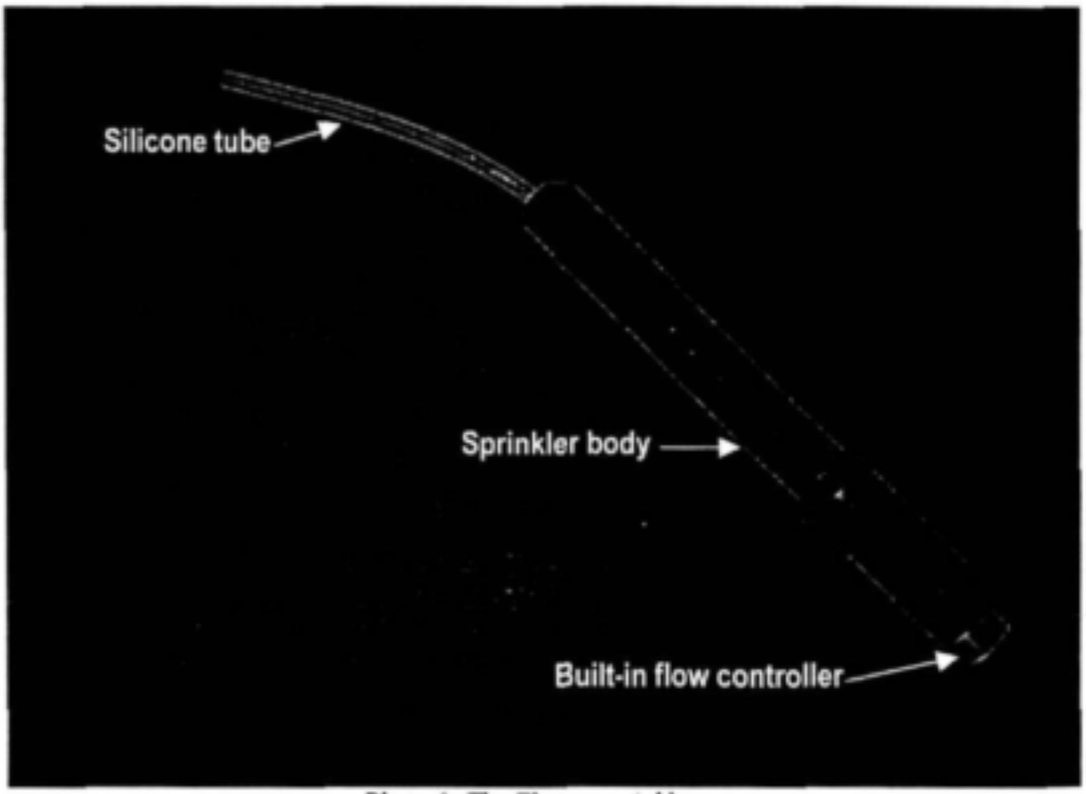


Photo 1: The Floppy sprinkler

It is important to obtain a measure of the application uniformity of an irrigation system. A literature review was performed on the uniformity parameters Coefficient of Uniformity (CU), Distribution Uniformity (DU) and the Scheduling Coefficient (SC). Obtaining high CU and DU values in-field has a direct influence on the potential yield of the crop and the total cost of an irrigation system. Irrigation evaluations at Silverton were performed during four time periods through the day, with tests starting at 06:00, 12:00, 18:00 and 24:00. The different time periods were selected to determine the influence of climatic variance and reflect the difference of irrigating at night and during the day. The CU and DU results were similar for the three systems with the Floppy sprinkler obtaining higher mean values than either of the impact sprinklers for the trials at Silverton. At Komatipoort only midday tests were performed with the impact sprinkler giving higher uniformity coefficients than the Floppy sprinkler.

The scheduling coefficient is an indicator of how low the application is in the driest portion of the field. The Floppy system achieved better values of scheduling coefficient than either of the impact sprinkler systems when viewing the entire data set of the trials at Silverton and Komatidraai. This indicates that the portions of the block irrigated by the Floppy sprinkler that receive the least water are less critical than in the case of impact sprinkler configuration.

A range of efficiencies can be measured in an irrigation system with the conveyance of water from a source, through the system, exiting the emitter, to the root zone of the plant. The efficiency that is of prime interest when evaluating sprinkler performance is the application efficiency, which is the ratio of water reaching the crop canopy to the volume of water exiting the emitter. A review of published evaporation studies is documented to provide an indication of typical losses from a sprinkler system. The application efficiency of the Floppy sprinkler operating on a permanent layout was found to be significantly higher than that of either of the impact sprinklers operating on a dragline layout in both the Silverton and Komatidraai trials. The climatic factor with the greatest influence on the application efficiency for the Silverton evaluations was the solar radiation. Very important to note is that although the CU for one system could be similar or poorer than another system, it should be considered in conjunction with the application efficiency to determine sprinkler selection. Utilising only the CU to select a suitable sprinkler, as is the practice of some designers, is not reviewing what occurs in an irrigation system in a holistic manner. By utilising application efficiency in the design process, the system may be designed either as a permanent, dragline or semi-permanent system. A system operating on a semi-permanent system cannot be designed in the same way as a permanent system since the losses typical in such systems differ.

Because the impact and Floppy systems operate on a dragline and permanent layout respectively the influence of microclimate formation was investigated. It was found that microclimate formation in a permanent system plays an important role in reducing losses in a sprinkler irrigation system. The performance of the impact sprinkler in terms of application efficiency was greatly enhanced when operating on a permanent layout. In addition it was found that the droplet size, influence of wind and system operating pressure contribute significantly in losses and application distribution. The most important factor to consider when analysing the effect of wind is the pressure in relation to the nozzle diameter and pressure variation is probably the most significant variable affecting irrigation uniformity. It could not be shown that the difference in droplet size for the impact and Floppy sprinklers was significant.

A cost analysis to determine the total cost of the permanent Floppy and dragline impact sprinkler systems was performed. The capital cost of a dragline system is generally considerably lower than the permanent system. By incorporating labour, maintenance, life expectancy, pumping costs and a water tariff the total cost of the Floppy system was found to be less than that of the dragline impact sprinkler systems.

Further evaluations that will challenge other accepted practices and standards in the irrigation fraternity are proposed at the end of the document. It is hoped that the results of the evaluations performed provide valuable information for designers and manufacturers and that the efficiency and operation of irrigation in South Africa will be improved through the publishing of this document.

2. INTRODUCTION

The impact sprinkler operating on a dragline system has become the standard method for irrigating many crops in South Africa. The Floppy sprinkler, working on a different principal and developed in South Africa, is marketed for similar applications on a permanent layout. Preliminary evaluation work performed by the ARC - Institute for Agricultural Engineering (1998), and funded by the Water Research Commission (WRC), indicated that the Floppy sprinkler system achieves higher application efficiencies relative to the impact sprinkler operating on a dragline system, when applying water to the ground. These results could however not be conclusively accepted without further testing and validation since insufficient repetitions of the test were performed.

A contract was entered into between the Institute for Agricultural Engineering and the WRC to perform further evaluations on commonly utilized impact sprinklers and the Floppy sprinkler to establish the in-field performance of the different emitters operating on their respective systems. By determining the efficiency of sprinkler irrigation emitters in their associated design layout, guidelines can be established for selecting emitters, particularly in water scarce regions.

2.1 Motivation

South Africa is a water scarce country, and the water engineering fraternity is being challenged to allocate its attention not only to meet increasing demand with increased supply but also to manage the demand of the various sector consumers. If growing water demands in South Africa are not curbed the country will face serious water shortages within the next few decades (Schreiner, 1998). Efficient water use is not only necessary because South Africa has limited water resources, but also because of limited financial and economic resources. The premature development of water infrastructure imposes opportunity costs on scarce financial resources that South Africa cannot afford (Schreiner, 1998).

To make a significant difference to the current water use pattern, the irrigation sector should be the initial focal point since it consumes more than 50% of the available water resources in South Africa (Van der Merwe, 1998). The proposals which form the foundation of the new water policy include the intention to provide for a quasi market in water rights (Vink, 1998). This can go some way to ensuring that water is allocated to its highest and best use. If the irrigation fraternity is to receive a reliable allocation of South Africa's water resources it will be necessary for agriculture to provide signals in the market that it is able to compete with other sectors in terms of beneficial utilization of water.

The field evaluation of irrigation systems as conducted by the Institute for Agricultural Engineering has the potential to contribute significantly to the improved efficiency of irrigation in South Africa. The goal of the evaluations are not to provide a purely physical comparison of irrigation products, but to challenge accepted practices followed by irrigation designers, manufacturers and farmers.

2.2 Scope of Work

The evaluations performed and reviewed in this document encompass tests on three sprinkler systems, as they are utilized in-field. The sprinklers tested were the black pop-up Floppy sprinkler on a permanent layout and two impact sprinklers. For this set of evaluations the two impact sprinklers will be referred to as impact sprinkler A and impact sprinkler B. All tests on these two impact sprinklers were performed on a dragline system unless otherwise stated, as in the microclimate formation tests, where some tests were performed on a permanent sprinkler system. The evaluations involve determining the efficiency with which irrigation water is applied, and determining various parameters that indicate the uniformity of the application. The tests were extended to provide further information on why efficiencies varied under different climatic conditions, and for different systems. Several literature sources were reviewed to establish whether the results and conclusions achieved are in keeping with international findings. A cost study and statistical analysis were performed to provide a more holistic perspective of the evaluations and to substantiate results.

3. METHODOLOGY

The goal of the evaluations on the impact and Floppy sprinklers were to determine the hydraulic performance of the three systems. Field evaluations and standard laboratory tests were performed to evaluate the emitters in their respective layouts at various pressures and subject to dynamic climatic conditions.

3.1 Field Tests

To establish the efficiencies of the various systems in-field tests were performed at the Institute for Agricultural Engineering, Silverton and at Transvaal Sugar Limited (TSB) in Mpumalanga. In order to eliminate the influence of performing evaluations under different climatic conditions the tests on the three systems were performed simultaneously. The systems were set out as shown in Figure 3.1 and Figure 3.2 for the Floppy and impact sprinklers respectively. All dimensions in these Figures are in metres. The Floppy system was installed with 12 sprinklers, as shown in Figure 3.1, to simulate the permanent layout. The single impact sprinklers were evaluated in two identical test areas as shown in Figure 3.2. The impact sprinklers were positioned on three metre moveable standpipes and during each test allowed to operate from each of the corners A, B, C and D for equal time periods of one hour. This layout simulated the dragline system that is widely utilized for irrigating sugar cane.

3.1.1 *Floppy sprinkler*

The black plastic pop-up Floppy sprinkler was utilized in the evaluations. Each sprinkler is fitted with a flow controller designed to deliver 745 liters per hour between 200 and 500 kPa. The pop-up tube is made of Silopren which has an outdoor life expectancy of more than 30 years (Herrmann, 1997). The system layout in the field is a triangular spacing of 15 m between sprinklers and 12 m between laterals. The black pop-up sprinklers are installed permanently on four metre aluminum standpipes. The laterals and sub-mains are buried to facilitate field access and the burning of the sugarcane before harvest. The system is designed to operate above 200 kPa, and due to the flow controller provides an almost constant delivery for pressures above this value.

3.1.2 *Impact sprinkler*

Several impact sprinklers, brass and plastic, with various nozzle sizes are available on the South African market. Two impact sprinklers were selected for this series of evaluations since they are widely utilized sprinklers for irrigating sugarcane in the

Mpumalanga region on a dragline layout. The crop and region were selected since the Floppy sprinkler is also utilized to irrigate sugarcane in Mpumalanga. Transvaal Sugar Limited utilizes both systems extensively and the Institute for Agricultural Engineering's good relationship with TSB opened the door for evaluations to be undertaken in that region. The two impact sprinklers each had a single 11/64" nozzle. The brass nozzles were fitted with a stream straightener and the spreader was blocked with a plug supplied by the product distributor. Both sprinklers are designed to operate at a pressure of 350 kPa on an 18 m x 18 m square grid spacing. The system operates on a dragline system with the equivalent of 2,58 sprinklers per hectare.

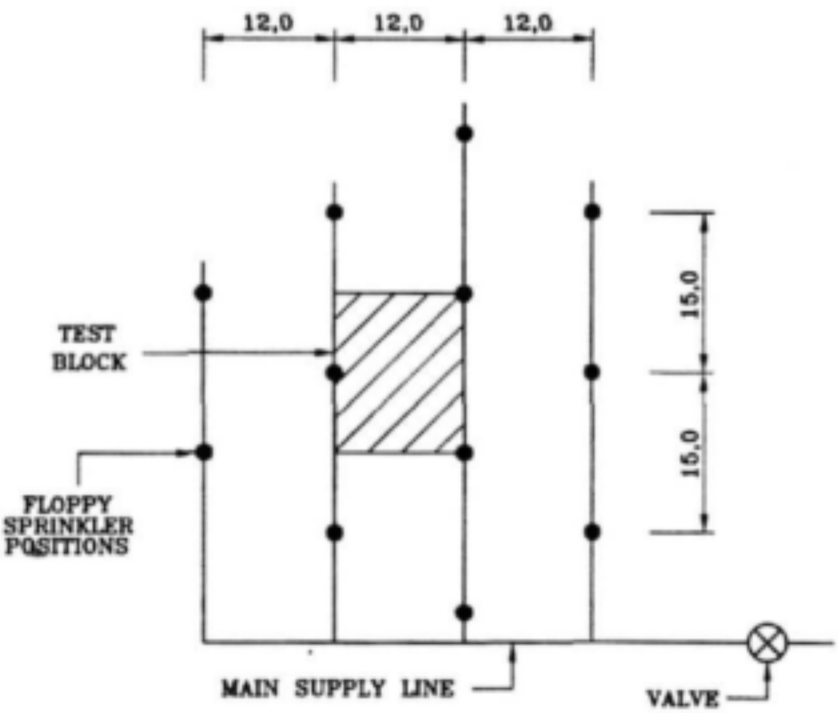


Figure 3.1: Field layout of Floppy sprinkler system

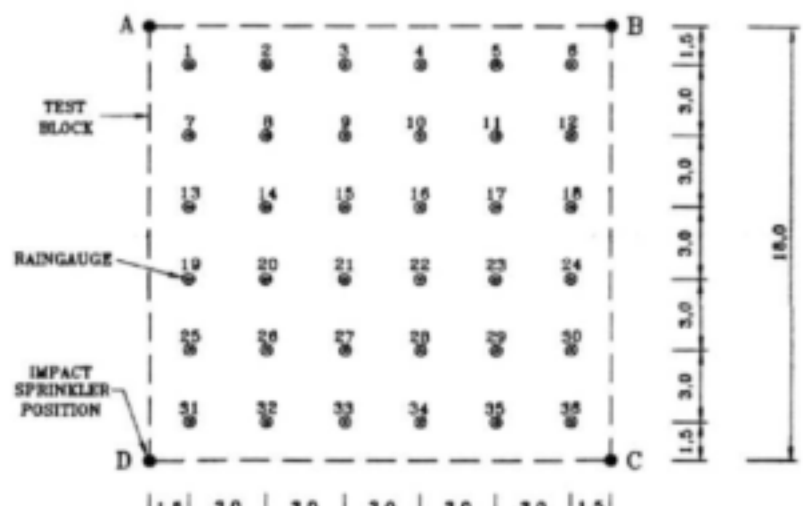


Figure 3.2: Field layout of impact sprinkler blocks showing raingauge positions

Raingauges were set out in the test block to measure the amount of water being applied to the ground. The raingauges were placed on a 3 m x 3 m grid, indicating that each gauge represents an area of 9 m 5. The layout of the raingauges in the irrigation blocks can be seen in Figures 3.2 and 3.3. The rain gauges were positioned 0,3 m above ground level and it was ensured that no vegetative interception of irrigation water occurred. The test duration period for the irrigation evaluations was two and four hours for the Floppy sprinkler and impact sprinklers respectively. The four hours for the impact sprinkler was necessary to allow one hour stand times on each of the corners A, B, C and D of the test block. This equates to the equivalent of one hour irrigation on the test block, which can be compared to a permanent system.

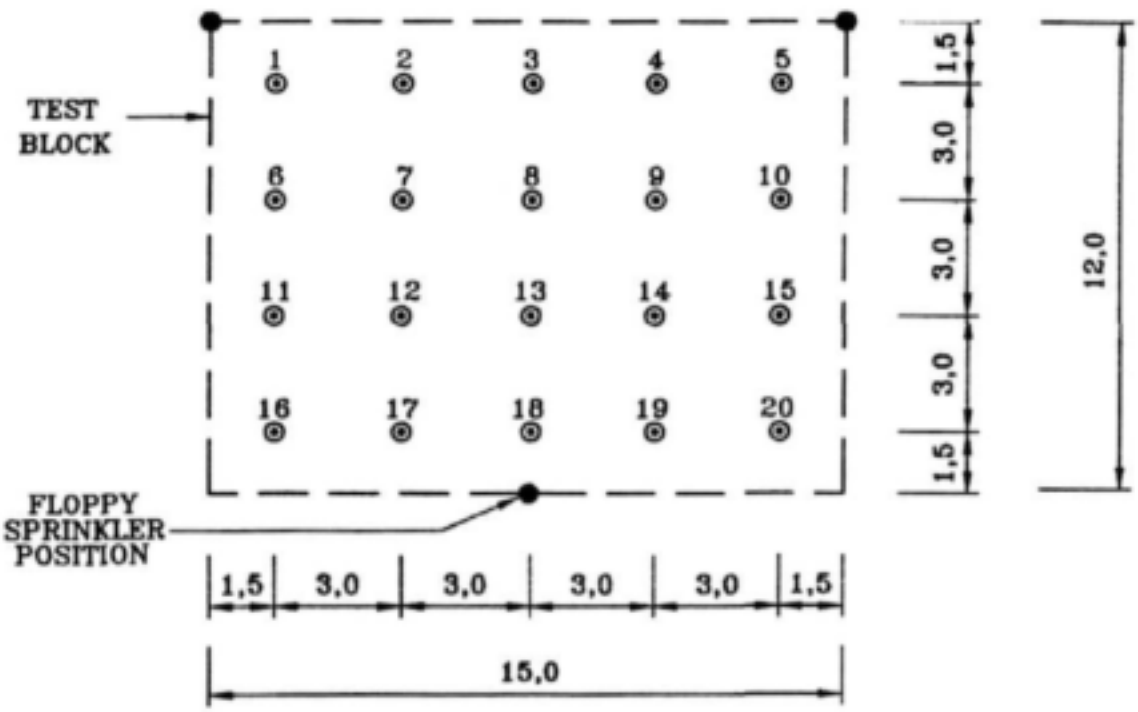


Figure 3.3: Field layout of the Floppy sprinkler block showing the raingauge positions

3.1.3 *Data measurement*

It was necessary to calibrate the raingauges utilized in the evaluations in order to ensure that accurate measurements of water depth applied to the ground were recorded. All raingauges had identical catch surface areas and the calibration of one raingauge, that was utilised for all measuring, was compared to the actual mass of water in the raingauge. This was achieved by massing volumes of water, placing the water in a rain gauge and reading off the depth of water. The mass of water was converted to an actual volume and compared to the depth measurement in the raingauge. It was determined that the calibration of the measuring raingauge was on average within 1,65% of the actual volume of the water.

For measuring the pressure at the sprinkler head, calibrated glycerin pressure gauges were installed approximately 100 mm below the sprinkler base. This allowed effective reading and control of the pressure during the trials. The flow through the emitter was determined by installing calibrated industrial flow meters in series with the supply line at the base of the standpipe. The calibration procedure yielded calibration factors specific to each flow meter, which could be multiplied by the difference between the final and initial flow meter readings to yield the total volume of water exiting the sprinkler emitter.

In the field the irrigation system performance is subject to climatic conditions. One sprinkler can perform remarkably differently in humid, windless, cool conditions to another time period with dry, windy, hot atmospheric conditions. A Campbell scientific automatic weather station was therefore instituted to record several parameters including relative humidity, dry bulb temperature, wind speed and direction, and solar radiation. Recordings of maximum, minimum and mean values of each were recorded at 15 minute intervals.

3.2 Laboratory Results

The laboratory evaluations were performed on the Sprinkler Test Bench in the Irrigation Laboratory of the Institute for Agricultural Engineering. The goal of the trials was to determine the coefficient of uniformity and the distribution uniformity of the Floppy and impact sprinklers on a single-leg test under laboratory conditions. This single leg test was performed in accordance with American Society of Agricultural Engineers Standards (ASAE, 1998).

The three sprinklers were evaluated at the standard height of one meter. Each sprinkler was tested individually on the test bench, which consists of a large splash cover mounted around the sprinkler position with an opening in-line with the single-leg of 0,25 m x 0,25 m catch cans at 0,25 m centers extending 25 meters. The square catch cans facilitate water flow into calibrated tubes that are electronically measured. The pressure at the sprinklers is regulated electronically at the specified test pressure.

4. PERFORMANCE PARAMETERS

4.1 Application Uniformity

The purpose of a sprinkler system is to distribute water evenly over the surface of the soil in such a manner that there can be absorption without runoff. Although an absolutely uniform application is not possible, it can be approached under field conditions. In evaluating an irrigation system it is essential to obtain a measure of the application uniformity.

4.1.1 *Literature review*

The most widely accepted measure of irrigation uniformity is J E Christiansen's coefficient of uniformity (CU). In 1941 Christiansen introduced the "Coefficient of uniformity", which had been developed from a study including more than 300 tests on sprinklers. The uniformity coefficient expressed as a percentage is defined by the equation:

$$CU = 100\left(1 - \frac{\sum d}{m.n}\right)$$

where d is the deviation of individual observations from the mean value m, and n is the number of observations (Christiansen, 1941). An absolutely uniform application is then represented by a uniformity coefficient of 100 percent, and a less uniform application by some lower percentage.

There are three important features of the CU formula that should be recognised and considered when interpreting CU values (Zoldoske and Solomon, 1988). Due to the absolute value used in determining the parameter d, over- and under-watering are treated relative to the mean, and therefore equally. Secondly, the computation of d assigns penalties in a linear manner. This means that the penalty assigned to each catchment is in direct proportion to the amount by which it deviates from the mean. Some critics argue that large deviations should be assigned a proportionately larger penalty. A third feature of the CU is that it indicates on average how uniform the sprinkler application pattern is. It can give no indication of how bad a particular localised area might be, or how large that critical driest area might be.

Since the CU does not provide an indication of how low the under-watered portions of irrigation application are, the distribution uniformity (DU) was developed to provide a measure of this (Zoldoske and Solomon, 1988). This method sorts all data points in the overlap area and ranks them from low to high. The mean value for the lowest 25 percent divided by the mean value for the entire region yields the distribution uniformity. This method does not take into account the location of the water values or any benefit, which may be derived from larger applications immediately adjacent to the low values.

A further parameter utilised to provide an indication of the sprinkler system performance is the scheduling coefficient (Solomon, 1988b). The scheduling coefficient aids in establishing the dryness of the driest, or most critical, area in the irrigation block. The scheduling coefficient indicates the amount of extra watering needed to adequately irrigate the critical area.

To calculate the scheduling coefficient it is first necessary to determine the critical area in the water application pattern - the area receiving the least amount of water. This is calculated utilising the computer software program SPACE for Windows™. A sliding window is moved systematically over the entire set of water application values found in the test block as shown in Figure 4.1 (Zoldoske and Solomon, 1988). As the window moves through the overlap area, the values falling in the window are averaged. The values are stored, and the lowest mean value is identified. This low critical window value is then divided by the total overlap mean. When multiplied by 100 a coefficient in percent which directly addresses the size and magnitude of the critical area is obtained. The scheduling coefficient can be used as a multiplier to determine the length of time that a sprinkler system should be operated to achieve a target application. The scheduling coefficient can be mathematically represented as (Zoldoske and Solomon, 1988):

$$Z_a = 100\left(\frac{M'}{M}\right)$$

Where Z = sliding window coefficient and a = the window size (2%, 5% or 10%)
M' = the low critical window value
M = the mean overlap value

0.95	0.64	0.66	0.55	0.52	0.54	0.54	0.52	0.52
0.84	0.73	0.59	0.51	0.50	0.54	0.52	0.52	0.51
0.95	0.59	0.51	0.46	0.47	0.52	0.50	0.52	0.51
0.51	0.48	0.43	0.41	0.43	0.50	0.47	0.51	0.51
0.41	0.40	0.37	0.37	0.39	0.49	0.44	0.51	0.51
0.35	0.35	0.33	0.33	0.35	0.48	0.41	0.51	0.50
0.31	0.31	0.30	0.29	0.32	0.46	0.39	0.50	0.50
0.28	0.28	0.28	0.27	0.31	0.44	0.37	0.49	0.52
0.21	0.27	0.27	0.28	0.29	0.41	0.34	0.49	0.53

Figure 4.1: Sliding window within grid of irrigation application values (from Zoldoske and Solomon, 1988)

A non-quantitative means of viewing the overlap area utilised by the Center for Irrigation Technology at California State University is to have it graphically displayed utilising a shading technique or "Denso-gram" (Zoldoske and Solomon, 1988). This process transforms the actual catchment into various intensities of shades. This is done by setting the wettest area to the value of one, displayed as black, and setting a completely dry area to the value of zero, displayed as white. All other values fall between the extremities and are ascribed shading values corresponding the their relative position between zero and one. Although this method provides a "feel" for overall uniformity, it does not provide a qualitative means to measure uniformity.

A similar program has been developed by Crosby (1997) in South Africa utilising different colours to represent relative differences in application. Sprinkler application patterns can be viewed in conjunction with the CU and DU for the specific sprinkler spacing. The influence of altering the lateral or in-line sprinkler spacing, or operating pressure can be clearly seen. Rectangular, staggered or triangular spacing can be evaluated.

4.1.2 *Importance of CU and DU*

Based on the yield function utilised by Solomon (1990), the relationship between Christiansen's uniformity coefficient (CU) and sugar cane relative yield is shown in Table 4.1. The importance of a uniform application is evident when reviewing the potential yield of sugarcane.

Table 4.1: Uniformity yield relationship for sugarcane (from Solomon, 1990)

Coefficient of Uniformity (CU)	Sugarcane relative yield
1.00	1.00
0.95	1.00
0.90	0.99
0.85	0.98
0.80	0.97
0.75	0.95
0.70	0.93
0.65	0.90
0.60	0.86
0.55	0.82
0.50	0.77

The importance of these values of CU and their corresponding relative yield is that the relative crop yield does not vary significantly between CU = 80% and CU = 100%. This indicates that the South African Irrigation Institute standard guideline of recommending uniformity indicators greater than 80% as being acceptable is well informed. Only when the CU value reduces significantly in value does the yield reduce to unacceptable levels.

The importance of a high DU value can be established when reviewing the Centre for Irrigation Technologies economic research in Table 4.2. Initial investment costs increase with DU, while water and power costs decrease (Solomon, 1988a). Solomon (1988a) utilises a water cost of 1,2 USA cents per cubic meter and a power cost of 8 cents per kilowatt hour. The water and power cost savings amount to approximately USA $ 1,40 per acre/year for each percentage point of DU improvement (1 hectare = 2.47 acres). This is enough to pay back the increased cost of the higher DU. In agricultural areas with higher water costs, the savings due to improved efficiencies would be even higher. For this example the lowest annual cost coincides with the highest DU value.

Table 4.2: Irrigation equipment, water and power costs for a range of distribution uniformities (from Solomon, 1988a)

Distribution Uniformity (DU)	Initial cost ($/acre)	Investment ($/acre/yr)	Power ($/acre/yr)	Water ($/acre/yr)	Total ($/acre/yr)
94%	809	129.26	19.34	36.23	184.83
92%	798	127.52	20.73	37.01	185.26
90%	800	127.88	22.89	37.84	188.61
88%	795	127.06	23.91	36.69	189.66
86%	788	125.98	25.76	39.59	191.33
84%	780	124.66	27.84	40.54	193.04
82%	775	123.77	30.14	41.53	195.44
80%	774	123.63	32.59	42.56	198.78

Many farmers and designers are under the impression that to increase the DU to very high uniformity levels the increased initial investment cost of a system would be inhibitive. Table 4.2, however, shows that an increased initial investment cost, with time, is compensated for by reduced power and water costs. This table suggests that achieving a high DU is justifiable, not only in engineering terms, but in financial terms.

4.1.3 *Laboratory results*

Typical guidelines that designers are provided with are that sprinklers with a CU > 84% should be selected (Viljoen, 1997). This coefficient is determined for sprinklers under laboratory conditions. The range of CU values and their corresponding performance rating are tabulated in Table 4.3. Although the concept of low values is relative, values of DU < 60% are generally considered low and a value of DU > 75% is recommended (Keller and Bliesner, 1990).

Table 4.3: CU coefficients of uniformity (Viljoen, 1997)

%	Performance rating
> 90	Excellent
80 – 90	Good
< 80	Unacceptable

Different sprinklers can be compared in the laboratory because they are tested under similar conditions, namely no wind, controlled pressure and three test repetitions. The test results provided by the ARC-Institute for Agricultural Engineering enable designers to compare sprinklers at different working pressures and spacing. Tests were conducted at the recommended operating pressure of 350 kPa for the impact sprinklers and at 250 kPa for the Floppy sprinkler as well as 50 kPa below and above these recommended pressures. Table 4.4 shows the CU and DU values achieved on the single leg Sprinkler Test Bench at Silverton at an internationally accepted operating height of one metre. Because the sprinklers are installed at greater heights in practice, another test was also performed on a height of two metres at the recommended operating pressures of the respective sprinklers.

Table 4.4: CU and DU laboratory results (%)

Height (m)	Pressure (kPa)	Impact sprinkler A (Dragline system)		Impact sprinkler B (Dragline system)		Floppy (Permanent system)	
		CU	DU	CU	DU	CU	DU
1	200	-	-	-	-	69	46
	250*	-	-	-	-	70	53
	300	69	60	69	62	70	45
	350**	74	67	70	64	-	-
	400	76	68	72	62	-	-
2	250*	-	-	-	-	84	74
	350**	72	68	70	62	-	-

*Recommended pressure for Floppy sprinkler.

**Recommended pressure for impact sprinklers.

The CU and DU were higher for the impact sprinklers at the recommended operating pressure of 350 kPa than the Floppy at its normal operating pressure of 250 kPa. Both sprinkler types yielded low CU and DU values of 74% and 70% for the impact sprinklers and 70% for the Floppy sprinklers at their respective recommended pressures. That is well below the accepted norm of 84%.

Only the Floppy sprinkler showed a significant increase in CU due to the increased height of two metres mainly because of the increase in the wetting radius. The wetted radius increased with more than 10% for the Floppy, comparing to the 2% increase of the impact sprinklers. It must, however, be noted that the crop is not always that much lower than the sprinklers.

It must also be pointed out that the normal selection procedure to test sprinklers on the Single Leg Test bench is to select three new sprinklers at random; to determine their distribution patterns and to select the "average" sprinkler for the further tests of CU, DU, etc.

The impact sprinklers were selected on that basis because during a previous study (unpublished results), 50 impact sprinklers were tested and only a marginal difference in CU values were obtained.

With the three selected Floppy sprinklers, the distribution patterns were not consistent and after investigation it was found that the wetting patterns were not smooth concentric circles. The CU values therefor also varies (between 63% and 75%) because the CU was calculated on the value of a single leg test and it depends on the diagonal that was tested at that time. The result in Table 4.4 is where the Floppy sprinkler was turned through 90° every 5 minutes during the test. Consistency was also obtained after a run-in time of the sprinkler, after which concentric circles were measured. The CU measurement was also repeatable after the run-in time. Field evaluations were entered into to determine how the sprinklers performed at farm level, at their correct operating heights.

4.1.4 *Field evaluations*

The initial set of field evaluations was performed at Silverton on the three systems. The tests were performed during four time periods through the day, with tests starting at 06:00, 12:00, 18:00 and 24:00. The different time periods were selected to determine the influence of irrigating at night and during the day, and to establish the variation in sprinkler system performance due to changing climatic conditions. Each test was repeated three times and has the corresponding mean climatic data adjacent to the uniformity values. Table 4.5 displays the CU and DU values for the field tests performed at Silverton.

Table 4.5: CU and DU values (%) for the system field evaluations performed at Silverton during four time periods during the day with the associated mean climatic data

06:00 Test

Test no.	Impact sprinkler A (Dragline)		Impact sprinkler B (Dragline)		Floppy (Permanent system)		Climate			
	CU	DU	CU	DU	CU	DU	T	RH	WS	Rad
1	80,0	63,8	74,2	59,2	78,2	69,8	14,73	50,07	0,49	214,57
2	78,5	68,6	76,5	63,2	77,9	72,8	14,39	57,28	0,60	198,12
3	75,9	65,6	77,4	61,6	80,8	71,1	15,35	69,09	2,04	199,80

12:00 Test

Test no.	Impact sprinkler A (Dragline)		Impact sprinkler B (Dragline)		Floppy (Permanent system)		Climate			
	CU	DU	CU	DU	CU	DU	T	RH	WS	Rad
4	83,8	78,9	81,9	71,1	81,4	79,5	21,91	50,55	2,88	444,09
5	70,5	58,3	68,1	51,4	78,7	71,2	25,47	32,83	3,16	594,78
6	72,2	58,8	71,0	54,0	79,2	71,4	29,29	19,28	1,66	652,03

18:00 Test

Test no.	Impact sprinkler A (Dragline)		Impact sprinkler B (Dragline)		Floppy (Permanent system)		Climate			
	CU	DU	CU	DU	CU	DU	T	RH	WS	Rad
7	72,5	58,1	72,3	53,9	80,5	74,6	19,54	40,02	1,36	1,44
8	80,6	71,4	79,0	69,3	76,4	67,9	18,84	50,13	1,02	1,25
9	80,7	76,3	79,5	73,6	77,8	68,3	15,73	77,09	0,15	2,71

24:00 Test

Test no.	Impact sprinkler A (Dragline)		Impact sprinkler B (Dragline)		Floppy (Permanent system)		Climate			
	CU	DU	CU	DU	CU	DU	T	RH	WS	Rad
10	79,9	72,8	78,5	67,4	78,5	72,3	14,52	71,90	3,44	0,02
11	80,6	73,6	77,0	65,4	75,3	65,5	12,29	68,49	1,15	0,00
12	75,6	73,5	75,2	71,2	73,8	67,1	12,76	51,50	0,05	0,00

The climatic conditions were recorded for the test duration, and are abbreviated as follows:

T - Mean dry bulb temperature (°C)
RH - Mean relative humidity (%)
WS - Mean wind speed (m/s)
Rad - Total solar radiation (W/m²)

The CU values for the three systems range in value between 68 and 84 %. These values are acceptable for field evaluations. The values are generally higher than the values obtained in the laboratory. This is not considered standard since acceptable results achieved under field conditions are generally 10% lower than acceptable values under laboratory conditions (Scott, 1997). The reason for the difference in values is that two tests were performed at different heights. The laboratory tests were performed at a height of one metre, while the in-field impact sprinkler trials were performed with at an elevation of three metres. The DU values range between 51 and 80% for the three systems. A DU of 51% indicates that the mean of the lowest 25% of the readings is approximately half the mean of the entire block. A low mean DU indicates the influence of critical points in the irrigation application block, but does not necessarily indicate critical areas within the irrigation block as the scheduling coefficient does. One low application may benefit from an adjacent large application, and the effect of a low DU could be significantly reduced. A large variation in DU within the data set indicates sensitivity of the sprinkler performance to climatic variables.

The relationship of the uniformity indicators to the specific climatic parameters cannot easily be established due to the continually varying weather, which is a function of several variables. Controlled conditions or a computer programme, where variables can be changed independently, would facilitate this. Literature has been reviewed and the influence of climatic conditions on the performance of sprinkler systems are included in this report. The statistical analysis reviewed in section 4.3 provides an indication of which climatic factors influence the uniformity indicators to the greatest degree.

The maximum, minimum and mean values of CU and DU are tabulated in Table 4.6. These values provide an indication of how the uniformity of the application varies due to irrigating at different times during the day or due to varying climatic conditions. The percentage difference indicated in the last row of Table 4.6 indicates the percentage difference in the maximum and minimum values.

Table 4.6: Maximum, minimum and mean values of CU and DU for the system field evaluations performed at Silverton (%)

	Impact sprinkler A (Dragline system)		Impact sprinkler B (Dragline system)		Floppy (Permanent system)	
	CU	DU	CU	DU	CU	DU
Maximum	83,8	78,9	81,9	73,6	81,4	79,5
Minimum	70,5	58,1	68,1	51,4	73,8	65,5
Mean	77,6	68,3	75,9	63,4	78,2	71,0
% Difference	15,9	26,4	16,8	30,2	9,3	17,6

The mean values of CU for the three systems are very similar and acceptable for in-field results. The uniformity values have a greater range for the impact sprinklers than for the Floppy Sprinkler. This is indicated by the lower minimum values and lower mean DU values. The lower percentage difference in maximum and minimum uniformity values indicates that the CU and DU of the Floppy sprinkler are less sensitive to irrigating at different times of the day or climatic variations than the impact sprinklers.

The CU and DU values obtained from the trials at Komatidraai are tabulated in Table 4.7. This table shows values similar, although slightly higher than the values obtained at Silverton. The values of CU and DU are particularly high for impact sprinkler A in this set of evaluations. The mean CU values from the previous report to the Water Research Commission (ARC-Institute for Agricultural Engineering, 1998) were 72% for the Floppy sprinkler on a permanent layout, and 76% for impact sprinkler A on a dragline system.

Table 4.7: CU and DU values for the system field evaluations performed at Komatidraai

10:00 Test

Impact sprinkler A (Dragline)		Impact sprinkler B (Dragline)		Floppy (Permanent system)		Climate			
CU	DU	CU	DU	CU	DU	T	RH	WS	Rad
84,8	79,3	78,5	65,6	76,4	71,3	29,62	44,45	2,52	977,75
87,0	79,3	77,9	62,7	78,1	71,5	25,80	75,89	0,47	372,46

4.1.5 *Scheduling coefficient*

Values of scheduling coefficient were determined for the field evaluations performed at Silverton and Komatidraai. The values are tabulated in Tables 4.8 and 4.9. The scheduling coefficient can be used as a multiplier to determine the length of time that a sprinkler system should be operated to achieve a target application. The mean scheduling coefficient for the impact and Floppy sprinkler systems were 1,5; 1,8 and 1,3 respectively. These values indicate that the sugarcane should be irrigated 50%, 80% and 30% longer for the three systems to ensure that the portion of the field receiving the lowest application will have an application equal to the target application.

The scheduling coefficient should be utilised with caution in agricultural irrigation since it was developed primarily for turf irrigation. Turf is a lot less sensitive to overwatering than many agricultural crops and the use of the scheduling coefficient as a multiplier to determine stand times in a cycle would not always be recommended for agricultural irrigation. The parameter however remains a useful indicator of how low the application is in the most critical portion of the field.

Table 4.8: Scheduling coefficient values for the system field evaluations performed at Silverton during four time periods during the day

06:00 Test

Test number	Impact sprinkler A (Dragline system)	Impact sprinkler B (Dragline system)	Floppy (Permanent system)
1	1,7	2,0	1,2
2	1,5	1,8	1,3
3	1,5	2,1	1,2

12:00 Test

Test number	Impact sprinkler A (Dragline system)	Impact sprinkler B (Dragline system)	Floppy (Permanent system)
4	2,0	2,4	1,3
5	1,3	1,5	1,3
6	1,9	2,4	1,2

18:00 Test

Test number	Impact sprinkler A (Dragline system)	Impact sprinkler B (Dragline system)	Floppy (Permanent system)
7	1,9	2,3	1,2
8	1,5	1,5	1,3
9	1,3	1,3	1,2

24:00 Test

Test number	Impact sprinkler A (Dragline system)	Impact sprinkler B (Dragline system)	Floppy (Permanent system)
10	1,5	1,6	1,2
11	1,3	1,5	1,3
12	1,5	2,0	1,3

Table 4.9: Scheduling coefficient values for the system field evaluations performed at Komatidraai

10:00 Test

Test number	Impact sprinkler A (Dragline system)	Impact sprinkler B (Dragline system)	Floppy (Permanent system)
1	1,2	1,8	1,5
2	1,5	1,6	1,6
3	1,2	1,9	1,2

4.2 Application Efficiency

Efficiency is difficult to define since it is a concept that represents the maximising of inputs (Reinders, 1996). Total irrigation efficiency should be evaluated in terms of the movement of water from its source to the root zone of the irrigated crop. This movement can be regarded as three separate operations: Conveyance, system distribution and field application (Reinders, 1996). Conveyance is the movement of water from its source through the mains and sub-mains or canals to the farm block off-takes. The system distribution is the movement of water through the distribution system or canals to the emitter outlets and onto the soil surface. Field application is the movement of the water from the emitter outlets into the root zone of the crop. Figure 4.2 shows the efficiencies between the various components of an irrigation system schematically.

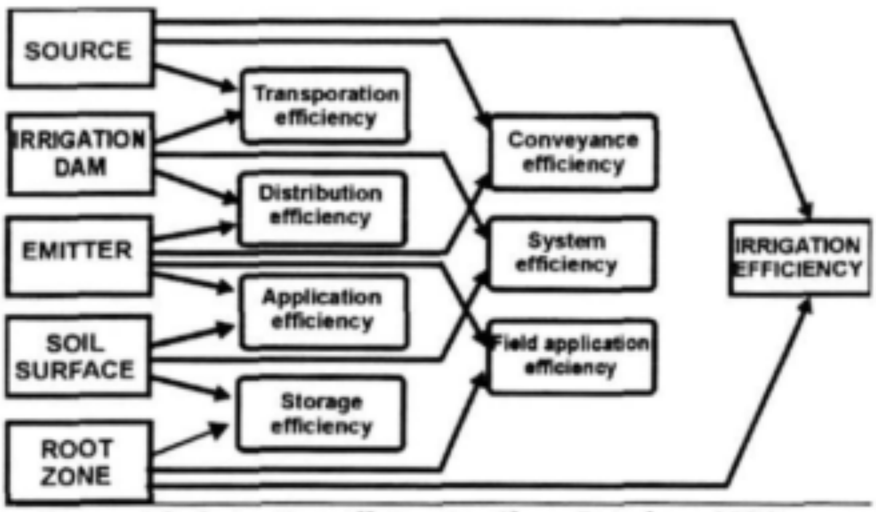


Figure 4.2: Irrigation efficiencies (from Reinders, 1996)

Since the performance of sprinkler systems are evaluated in this report the efficiency which is of paramount importance in this investigation is the ratio of the amount of water reaching the crop canopy or soil surface to the volume exiting the sprinkler emitter. This is termed the application efficiency (AE).

$$AE = \frac{Volume\ of\ water\ reaching\ crop\ canopy}{Volume\ of\ water\ exiting\ emitter}$$

4.2.1 *Literature review*

The primary losses associated with sprinkler irrigation, other than those due to over-watering, are direct evaporation from wet soil surfaces, wind drift, evaporation losses from the spray, system drainage and leaks (Solomon, 1988a). 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 (Kohl, Kohl and DeBoer, 1987). This loss is attributed to a combination of wind drift and spray evaporation, which together account for the application efficiency.

Spray evaporation can be defined as the fraction of total spray converted into vapour, and subsequently transferred to the atmosphere (Silva and James, 1988a). One definition of wind drift is the amount of sprinkler spray carried outside of the irrigated field. Irrigation engineers generally have thought that the evaporation component is the larger of the two components (Kohl, Kohl and DeBoer, 1987). Sprinkler irrigation evaporation losses have been the subject of numerous field, laboratory and analytical studies, and the loss values obtained from these studies were not defined in common terms as can be seen in Table 4.10.

Table 4.10: Review of Published Evaporation Studies (from Kohl, Kohl and De Boer, 1987)

Investigator	Year	Method	Evaporation definition	Evaporation range, %
Christiansen	1942	Catch can	Discharge-catch	1 - 42
Christiansen	1942	Thermodynamic		0.2 - 2
Frost and Schwalen	1955	Catch can	Discharge-catch	3 - 45
George	1955	Catch funnel	Increase in electrical conductivity	2 - 15
Kinzer and Gunn	1951	Measuring water droplet diameters in a moving column of air		Measuring rates of evaporation
Kraus	1966	Catch can	Increase in Na^+ content	3 - 9
Robinson	1973	Catch can	Increase in electrical conductivity	0.7 - 8
Sternburg	1967	Catch can	Discharge-catch	11 - 25
Till	1957	Catch can	Increase in electrical conductivity	0.7 - 2.7
Yazar	1984	Catch funnel	Discharge-catch	2 - 31

Kohl, Kohl and De Boer (1987) state that there were differences in definitions of evaporation and wind drift losses and in the accuracy of experimental techniques. Experimental loss values range from 2% to 40% with many values falling into the 10% to 20% range while the analytical and laboratory results were in the 1% to 2% range.

Seginer (1971) developed a resistance model to predict evaporation loss and found that spray evaporation was negligible relative to drift loss. Heermann and Kohl (1980) in Edling (1985) gave the range from several evaporation loss calculations as being 1% to 6% with most estimates being at the lower end.

Frost and Schwalen (1955) developed a nomograph to estimate evaporation that is still in use today. The nomograph for estimating evaporation spray losses is based upon approximately 700 tests under a variety of climatic conditions. The nomograph uses wind velocity, nozzle pressure and size, and the temperature and relative humidity of the air to estimate loss. Elevation of nozzle is not a variable in the estimate, and the tests were performed with impact sprinklers. The nomograph is shown in Figure 4.3.

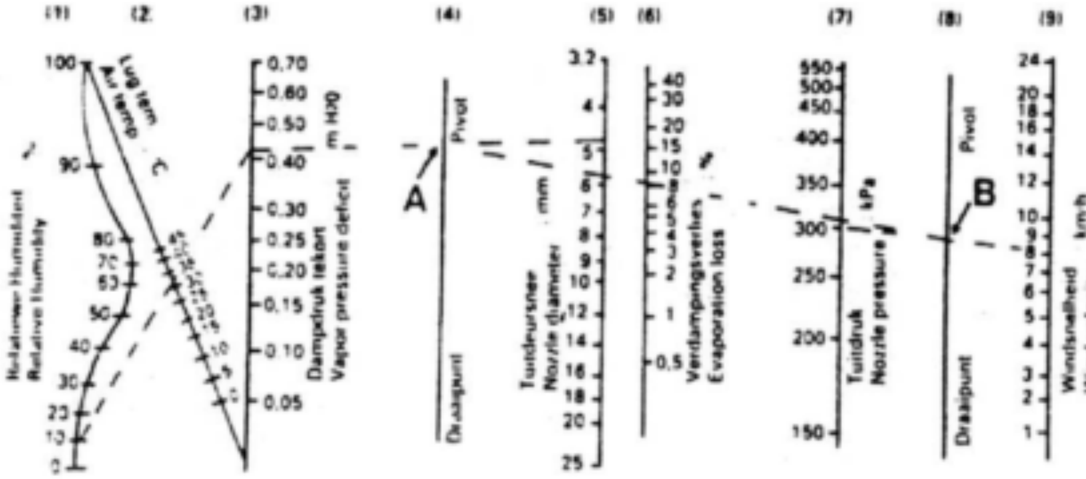


Figure 4.3: Nomograph for estimating the evaporation spray losses under various climatic and operating conditions in sprinkler irrigation (Frost and Schwalen, 1955)

For example, if the values are as follows:

(a) Relative humidity	10%
(b) Air temperature	32°C
(c) Nozzle diameter	4,8 mm
(d) Working pressure	300 kPa
(e) Wind speed	8 km/h

The evaporation loss can now be determined by using the Frost-Schwalen nomograph: Using values *a* and *b* on scales (1) and (2) respectively, a point can be located on scale (3). With this value and value *c* on scale (5), point A can be fixed on pivot (4). Using values *e* and *d* on scales (9) and (7) respectively *a* point B can be fixed on pivot (8). Connect A on pivot (4) and B on pivot (8) intersecting scale (6), to obtain the percent evaporation loss. This is ± 8%.

4.2.2 *Field evaluations*

The application efficiency is considered to be a critical parameter in evaluating the performance of an emitter. International trends in considering the efficiency of application are to rather define an effective rate of application which is case specific and has no fixed relationship to the CU value, but does consider the effectiveness of distribution (Scott, 1997). Tables 4.11 and 4.12 indicate the application efficiencies determined for the evaluations at Silverton and Komatidraai respectively.

Table 4.11: Application efficiency for the system field evaluations performed at Silverton (%)

06:00 Test

	Impact sprinkler A (Dragline)	Impact sprinkler B (Dragline)	Floppy (Permanent system)	Climate			
Test no.	AE	AE	AE	T	RH	WS	Rad
1	66,6	74,2	93,3	14,73	50,07	0,49	214,57
2	79,8	78,1	94,4	14,39	57,28	0,60	198,12
3	62,6	65,5	93,0	15,35	69,09	2,04	199,80

12:00 Test

	Impact sprinkler A (Dragline)	Impact sprinkler B (Dragline)	Floppy (Permanent system)	Climate			
Test no.	AE	AE	AE	T	RH	WS	Rad
4	56,6	57,0	83,0	21,91	50,55	2,88	444,09
5	40,6	46,0	71,0	25,47	32,83	3,16	594,78
6	27,8	30,5	68,1	29,29	19,28	1,66	652,03

18:00 Test

	Impact sprinkler A (Dragline)	Impact sprinkler B (Dragline)	Floppy (Permanent system)	Climate			
Test no.	AE	AE	AE	T	RH	WS	Rad
7	80,7	82,1	97,5	19,54	40,02	1,36	1,44
8	71,3	75,5	96,4	18,84	50,13	1,02	1,25
9	90,3	100,0	92,9	15,73	77,09	0,15	2,71

24:00 Test

	Impact sprinkler A (Dragline)	Impact sprinkler B (Dragline)	Floppy (Permanent system)	Climate			
Test no.	AE	AE	AE	T	RH	WS	Rad
10	82,0	85,1	88,5	14,52	71,90	3,44	0,02
11	82,0	85,3	94,7	12,29	68,49	1,15	0,00
12	90,2	89,2	89,5	12,76	51,50	0,05	0,00

Table 4.12: Application efficiency for the system field evaluations performed at Komatidraai

10:00 Test

	Impact sprinkler A (Dragline)	Impact sprinkler B (Dragline)	Floppy (Permanent system)	Climate			
Test no.	AE	AE	AE	T	RH	WS	Rad
1	50,6	47,0	65,3	29,60	44,45	2,52	977,75
2	43,5	46,4	65,8	35,00	35,48	3,88	970,63
3	71,1	71,7	80,9	25,80	75,89	0,47	372,46

The climatic conditions were recorded for the test duration, and are abbreviated as follows:

T	-	Mean dry bulb temperature (°C)
RH	-	Mean relative humidity (%)
WS	-	Mean wind speed (m/s)
Rad	-	Total solar radiation (W/m^2)

By coupling the physical evaluations with climatic data a valuable reference is provided for establishing which factors contribute significantly to the performance of the system. The difficulty is that the systems operate in a dynamic system subject to several variables, and conclusions made for one variable in one set of tests may not hold true in another set due to the influence of other variables. This occurrence can be rendered less significant by performing numerous repetitions of the same test and establishing a database of results. The statistical analysis in section 4.3 describes the relationship between application efficiency and the square of radiation. This relationship was established when analysing the Silverton data.

Frost and Schwalen's (1955) nomograph illustrates that losses from an emitter are directly related to the climatic variables of wind velocity, temperature and relative humidity. Wind velocity not only influences losses but also distorts the distribution pattern of the application as is discussed in section 5.3. A high relative humidity reduces atmospheric demand and therefore evaporation. Silva and James (1988b) stated that the atmospheric demand of downwind air is most sensitive to upwind relative humidity. Although evaporation does increase with temperature the increase is not dramatic (Edling, 1985).

When reviewing the results of the evaluations in Tables 4.11 and 4.12 it is clear that the losses experienced between emitter and the ground surface are generally high when compared to the values reviewed in literature and summarised in Table 4.10. One reason for the discrepancy in tabulated values and the values obtained in the present trials is the height at which the sprinklers were evaluated. The Floppy sprinkler operates at a height of 4 m and the impact sprinklers on a 3 m standpipe. This is contrary to American Society of Agricultural Engineers Standards, which stipulate a height of the main nozzle of 0,6 m above the average elevation of the tops of the four nearest collectors (ASAE, 1998). The Standards however continue to state that other heights may be used for special purposes, but in all cases the nozzle height shall be clearly displayed in the data. The motivation for the field evaluations being performed at the selected heights is that these are the design and installation heights utilised for the sugarcane crop, which at maturity approaches a height of 3 m. The influence of nozzle elevation is discussed by Edling (1985) who showed that smaller droplets are particularly sensitive to nozzle height, especially as the wind speed increases.

A second reason why the application efficiency values in literature and in the trials undertaken differ is that the impact sprinklers were evaluated on a semi-permanent system, as they operate in the field while the values in Table 4.10 were obtained from tests on a permanent system. The influence of the permanent system is the creation of a microclimate, which will be further discussed in section 5.1. This occurrence has a significant effect on the losses occurring while irrigating.

The mean results of application efficiency obtained in the field evaluations at Silverton are displayed graphically in Figure 4.4. This graph illustrates the variation in application efficiency during the progress of the day. These values were obtained during Spring 1998, and although values will vary seasonally it is expected that the relationship between time of day and application efficiency will remain basically the same during other seasons. The benefit of irrigating at night is evident due to the higher application efficiencies in the evening. Typical values of application efficiencies utilised at present in economic analyses utilise values of 60% and 75% for the impact sprinklers and Floppy sprinkler respectively. If irrigating for 24 hours each day, and reviewing Figure 4.4, values of 72% and 88% more accurately illustrate holistically what occurs. The graph in Figure 4.4 would be more accurately represented by a curve similar to the reference evaporation curve since application efficiency is a function of the atmospheric evaporative demand. The curve would pass through the mean application efficiency values for the specific tests at different times of the day.

As with the CU and DU values for the evaluations at Silverton the percentage variation between the maximum and minimum values of application efficiency are considerably lower for the Floppy sprinkler when compared to the impact sprinklers. These values are shown in Table 4.13.

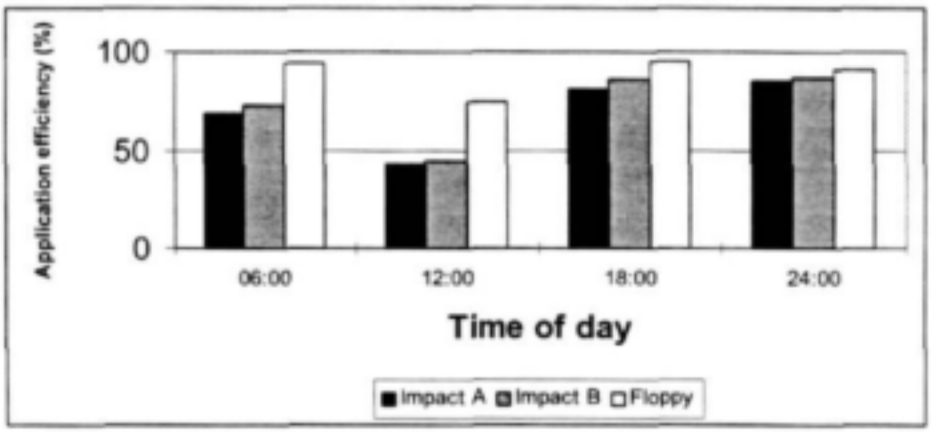


Figure 4.4: Mean Application Efficiency at different times of the day for the Silverton trials for the dragline impact sprinklers and the Floppy permanent system

Table 4.13: Maximum, minimum and mean values of application efficiency from the Silverton evaluations

	Impact sprinkler A (Dragline)	Impact sprinkler B (Dragline)	Floppy (Permanent system)
Maximum	90,3	100,0	97,5
Minimum	27,8	30,5	68,1
Mean	69,2	72,4	88,5
% Difference	69,2	69,5	30,2

Of specific interest in the trials at Komatidraai, Table 4.12, are that on two days relatively low humidity, high wind speeds, high temperatures and high radiation prevailed. These conditions resulted in low application efficiencies. Test 3, however, yielded relatively high application efficiencies for a midday evaluation since the cooler, windless, overcast, high humidity conditions were favourable for irrigating. Extremely high efficiencies were achieved in the Silverton trials for Test 9 where similar climatic conditions prevailed. This is also evident in Tests 5 and 6. The highest losses in the Silverton evaluations coincided with the lowest values of relative humidity and the highest radiation values illustrating the significant influence these variables have. This relationship with radiation is validated by the statistical analysis in section 4.3.2.

The ARC-Institute for Agricultural Engineering was able to refine its testing procedure in evaluating the sprinklers during four time periods through the day. It was determined that in evaluating the sprinklers for research projects at Silverton, two time periods beginning at 10:00 and 18:00 would be utilised in future. The initial would form the midday evaluation and the latter the night test. The 06:00 test experienced a relatively large range in climatic parameters and it will not be performed in the future. The 18:00 and 24:00 test results were similar, thus justifying the exclusion of one of these evening tests. The 12:00 test will be replaced by a 10:00 test since the earlier test allows the evaluation to occur during the warmest portion of the day.

4.3 Statistical Analysis

An analysis of the test results was performed by Müller (1999), a biometrician, to determine if the variations of parameters obtained in the evaluations were significant. The motivation behind obtaining these results is that it must be established by accepted methods that there is a meaningful or significant difference between sprinkler system performances before conclusions can be made.

4.3.1 *Method of analysis*

The stepwise regression approach analysis was utilised for each of the three dependant variables AE, CU and DU in analysing the Silverton field evaluations data set with the impact and Floppy sprinklers. The analysis was performed with the aid of the software package GENSTAT version 5.3 (Anon., 1993).

Stepwise regression is a multi-variable regression technique that automatically selects the parameters that contribute most significantly to variations in the dependent variables. Parameters that influence the three dependent variables AE, CU and DU are sprinkler system selection and the climatic factors such as temperature, relative humidity, wind speed and radiation. The efficiency and uniformity parameters may also be related to the square of these climatic factors. The stepwise regression method is an optimal model selection process.

4.3.2 *Results*

The analysis yielded meaningful variations with respect to the three systems. The climatic factors that contribute significantly to the variation in the dependent variables were not the same for each of the analyses. It was determined in the analyses that there is a significant difference in the performance of the permanent Floppy system when compared to the dragline impact sprinkler systems. Table 4.1.4 provides a summary of the results of the analyses.

In Table 4.1.4, the F-probability in the second column is an indication of the reliability of the regression performed. This value deems the regression meaningful and significant when $F_{prob} < 0{,}05$. The adjusted R- square, or R^2_a , varies between 0 and 100. This value indicates how closely the regression models what occurs in practice, and the R^2_a criteria are stricter than the standard R^2 criteria. As R^2_a approaches 100 the regression progressively becomes better, and values above 80 indicate that a prediction model could be considered. It should be noted that the regression results are for a specific data set and the trends may be different in other regions with other climatic data.

The non-linear radiation trend for AE in the Silverton trails shows a similar non-linear trend for the three systems. This means that in Figure 4.5, where application efficiency is plotted as a linear function of the square of radiation, the performance of the three systems is characterised by three parallel lines with differing y-axis intercepts. The Floppy sprinkler on a permanent layout performs significantly better than the two impact sprinklers on dragline systems. The equations describing the regressions for the three systems are in the form of y = c + mx and are:

Permanent	:	AE_P =	96,12	- 0,00009908 * rad^2
Impact sprinkler B dragline	:	AE_{ISB} =	81,47	- 0,00009908 * rad^2
Impact sprinkler A dragline	:	AE_{ISA} =	78,30	- 0,00009908 * rad^2

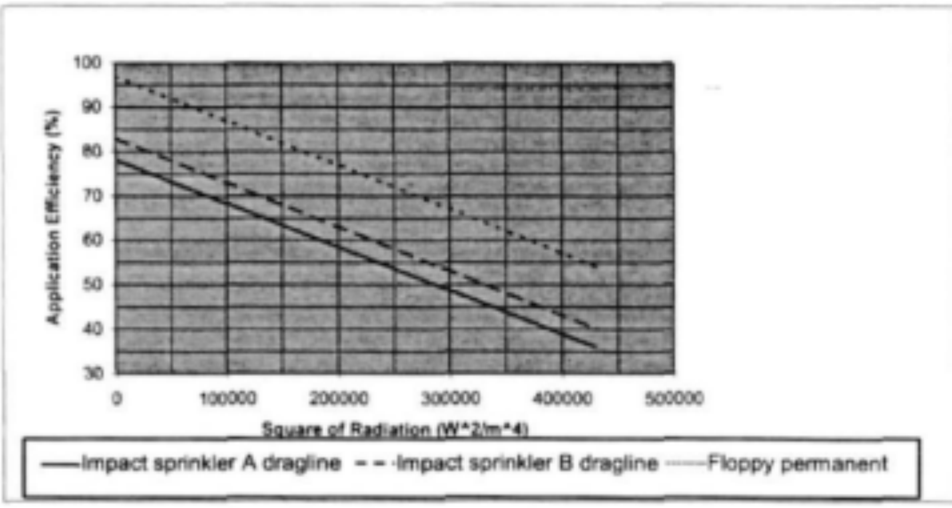


Figure 4.5: Plot of the Regression Curves of Application Efficiency at Silverton as a function of the square of radiation

The CU and DU for the field evaluations at Silverton were found to be a function of the combined sprinkler-relative humidity effect. This means that the relevant dependent variable is a function of relative humidity but differs depending on which system is being utilised. The uniformity coefficients for the Floppy at Silverton are consistently higher than for the impact sprinklers on a dragline system. Another way of viewing the relationship between performance indicating parameters and a specific climatic variable is that the system that performs significantly better is affected to a lesser degree by the variation of climate.

Table 4.14: Summary of statistical analysis for the system field evaluations performed at Silverton (from Müller, 1999)

Variables	F-prob	Adj R-square	Significant effect in model	Interpretation
AE	0,001	80,0	sprinkler square of radiation	Floppy has significantly higher AE compared to impact sprinklers.
CU	0,002	36,4	relative humidity sprinkler * relative humidity	Floppy has significantly higher CU compared to impact sprinklers.
DU	0,003	47,0	sprinkler relative humidity sprinkler * relative humidity	Floppy has significantly higher DU compared to impact sprinklers.

The microclimate formation tests had insufficient data to obtain meaningful conclusions, but indications were that the AE for the permanent sprinkler system are significantly higher than the AE for the dragline system. Although the data was insufficient for the Komatidraai trials, the incorporation of this data with the results from a previous report for the Water Research Commission by the ARC-Institute for Agricultural Engineering (ARC-Institute for Agricultural Engineering, 1998) allowed conclusions to be drawn. The data utilised is included in the Appendix of this report.

The AE results for the evaluations at Komatidraai show the same trend for the Floppy and impact sprinklers and if the results were plotted graphically it would have a significant difference in the value of the intersection of the curve with the vertical axis. These AE results are a function of relative humidity, and the Floppy system performs significantly better than either of the impact sprinkler systems as in the Silverton evaluations.

The CU values for the Komatidraai evaluations yielded a dependency on the atmosphere temperature. The Floppy and impact sprinklers showed similar trends through the temperature range, and if they were plotted graphically, their intercepts with the vertical axes would differ significantly. The CU values for the impact sprinklers are at Komatidraai constantly higher than that of the Floppy. The DU values for the Komatidraai evaluations differ in a meaningful manner with respect to their mean values and the impact sprinklers perform significantly better than the Floppy sprinkler system for this uniformity indicator. Although a marginal change, the results for CU and DU in the Komatidraai region are higher for the Floppy sprinkler than the impact sprinkler system.

5. FACTORS INFLUENCING PERFORMANCE PARAMETERS

Kraus (1966) stated that the difficulty in analysing sprinkler irrigation efficiency stems from the fact that losses occur in many ways and that part of these losses may only be apparent losses. These apparent losses may actually reduce evapotranspiration in both the sprinkled areas as well as in adjacent areas. Thus to analyse sprinkler irrigation efficiency completely, one must first separate quantitatively the component losses, evaluate the relationship between these losses and finally evaluate the influence of losses on nearby soil and vegetation.

5.1 Microclimate Formation

An evaluation of sprinkle irrigation efficiency should consider the effects of sprinkling on the microclimate (Silva and James, 1988a). It has been shown experimentally that sprinkler spray evaporation promotes changes in temperature and vapour concentration downwind from sprinkler laterals. (Mather, 1950; Longley, Garvin and Stark, 1983). Plants could be either beneficially or adversely affected by these changes depending on the existing climatic conditions and plant requirements. Since air temperature generally decreases downwind of sprinklers, cool-season plants growing in warm weather conditions would be beneficially affected, while warm-season plants could be adversely affected (Kohl and Wright, 1974 in Silva and James, 1988a).

Frost and Schwalen (1955) verified that in operating a single sprinkler alone, losses in the outer fringe area were not comparable with those occurring under field conditions with overlapping spray from adjacent sprinklers. Silva and James (1988b) developed a computer model for estimating spray evaporation and changes in microclimate downwind from a low pressure spray sprinkler. Utilising this model it was found that spray evaporation is most sensitive to droplet size, and moderately sensitive to relative humidity and sprinkler height. It was also observed that the vapour density of the downwind air is most sensitive to upwind relative humidity.

Research by Kraus (1966) yielded Table 5.1. This table demonstrates the appreciable difference in microclimate created by operating the sprinkler lateral. Except for Test 3, which was an early morning test, during which the relative humidity upwind from the lateral was quite high, the increase in relative humidity downwind from the lateral, due to the operation of sprinklers, was in the order of magnitude of 30 percent.

Table 5.1: Comparison of evaporative conditions upwind and downwind of operating sprinkler lateral under south wind conditions (from Kraus, 1966)

Test no.r	Relative humidity (%)		Saturation deficit	
	Upwind	Downwind	Upwind	Downwind
1	37	66	0.673	0.425
2	50	77	0.396	0.197
3	75	83.5	0.094	0.062
4	28	66	0.376	0.208
5	37	69	0.590	0.310

Kraus (1966) attempted to explain the effect of increased evapotranspiration in drift areas as compared with dry areas under relatively high wind conditions. Under relatively high wind conditions plants in dry areas tend to become stressed causing a partial closing in stomatal openings, and a subsequent reduction of evapotranspiration.

In the drift area plants were not stressed by wind conditions due to the fact that a wetter climate prevailed and evapotranspiration occurred at a relatively high rate. The reduction or increase in evapotranspiration in the drift area certainly depends on the microclimate environment as a whole, and wind velocity is apparently the single largest factor affecting this phenomenon (Kraus, 1966).

Solomon (1990) stated that a final management practice that can improve uniformity is the practice of irrigating blocks of several adjacent laterals simultaneously. A beneficial microclimate develops within the block, minimising wind distortion and losses due to wind drift and evaporation. Numerous field experiments have documented an improvement in uniformity due to this block effect.

Due to this block effect it is important to determine the influence of microclimate formation on the performance of the impact sprinklers. Setting up a permanent set of impact sprinklers together with a dragline configuration enabled this phenomenon to be evaluated. The two systems, the layout of which are shown in Figures 3.2 and 5.1, were evaluated simultaneously to ensure that the same climatic conditions prevailed for both systems. The results of the evaluations are tabulated in Table 5.2.

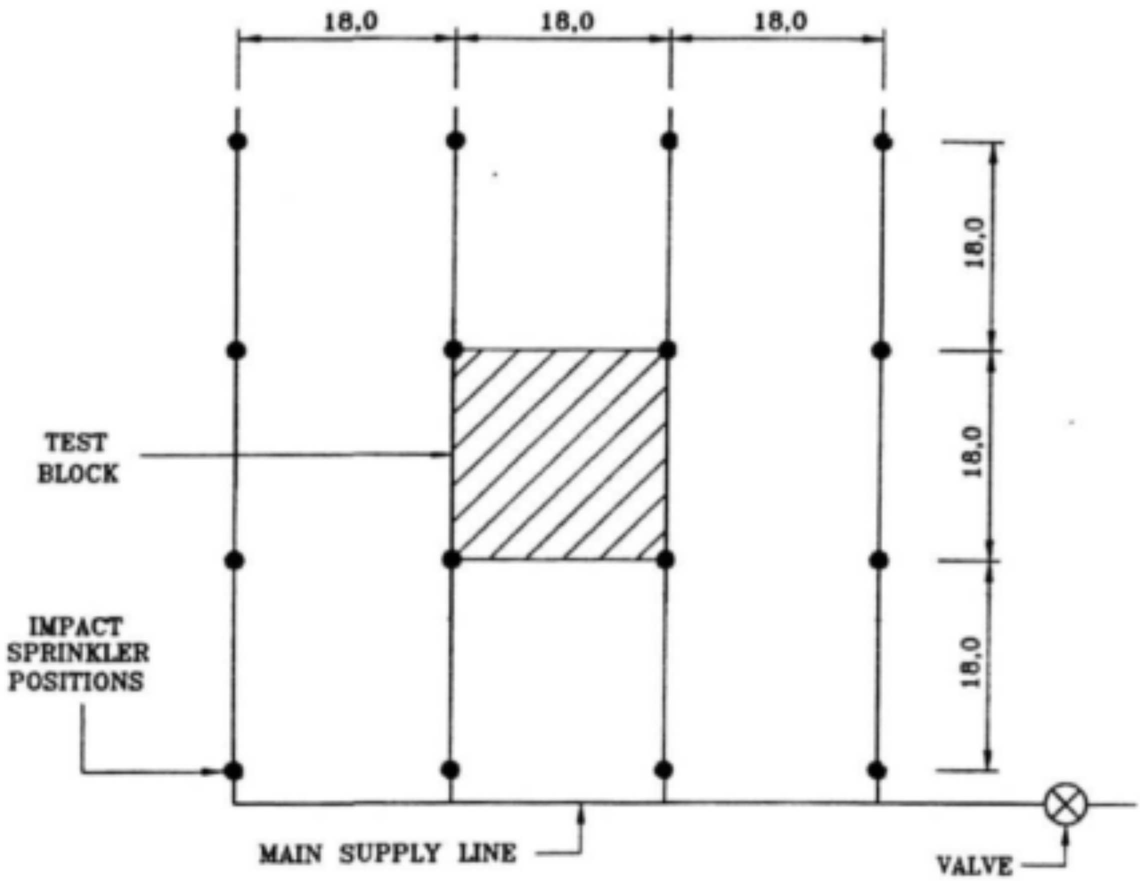


Figure 5.1: Layout of permanent set of impact sprinklers

Table 5.2: Application efficiency, CU and DU obtained in the microclimate formation tests at Silverton

Impact sprinkler A (Permanent system)			Impact sprinkler A (Dragline system)			Climate			
AE	CU	DU	AE	CU	DU	T	RH	WS	Rad
72,1	83,4	70,1	52,6	86,0	75,7	26,6	51,72	1,27	565,83
67,7	79,5	65,2	55,7	81,6	75,6	23,6	55.01	2,02	555,60
66,7	81,4	70,0	46,2	86,3	77,2	23,9	47,03	1,63	651,05

The microclimate formation evaluations were performed at midday when the effect of a permanent layout had its greatest effect. The results of application efficiencies achieved shows that the permanent system achieves application efficiencies of 30% more than the dragline system. This is comparable to the values achieved by the Floppy sprinkler for the midday test. This suggests that the Floppy sprinkler is not outperforming the impact sprinklers, but that the permanent sprinkler configuration is superior to the dragline system to a significant degree. The permanent impact sprinkler configuration is however expensive as was tested in these evaluations, although some farmers do utilise this system. If a permanent system for impact sprinklers were to be pursued, larger spacing, sprinklers and nozzles would reduce the financial implication. It would however be necessary to evaluate these systems in-field to ensure that efficiencies and uniformities are competitive with other permanent systems. There is at present some controversy over the possible losses in such systems due to the large wetted diameters and lower design irrigation applications.

Van der Ryst (1991) described the microclimate, when applying water at a high rate, as forming a "wall" of water and saturated air between the emitters and plant canopy. This was specifically for the center pivot and linear systems, but the analogy holds true for all overhead irrigation systems. The application of the Floppy system is similar to that of the large mechanised systems in that the water is applied permanently in a specific area for a certain time period and a saturated water dome is formed. Van der Ryst (1991) stated that only water at the surface of this dome is exposed to the vapor pressure deficit of the surrounding atmosphere.

Climatic conditions have a greater effect on an installation with a 1 mm/h application rate than one with a 3 mm/h application rate (Koegelenberg, 1999). The actual application depth of a permanent system is always greater than that of a dragline system if both systems have the same sprinkler type, operating pressure and nozzle size. The Floppy and impact sprinkler systems have design applications of 4.2 mm/h and 4.3 mm/h respectively when both operating on a permanent layout. The impact sprinklers apply less than this amount when operating on a dragline system. Irrigating with lower application rates may compound the effect of not having microclimate formation in a dragline system, and the influence of application rate on losses should be addressed in future studies.

5.2 Sprinkler Droplet Size

Water droplet size is an important consideration in the design of sprinkler irrigation systems. Christiansen (1941) showed that wind distorts the application pattern of a sprinkler. Research has shown that small droplets lead to distortion of spray patterns by wind and larger droplets are affected to a lesser degree (Hills and Gu, 1989). This is due to wind exerting a force proportional to the cross sectional area of the drop (a function of the drop diameter squared), while the inertia of the drop resisting the wind's force is proportional to its mass (a function of the drop diameter cubed) (Solomon, Zoldoske and Oliphant, 1996).

The amount of water that evaporates from a drop depends on the surface area of the drop, and on how long the drop is in the air (Solomon, Zoldoske and Oliphant, 1996). Irrigating equal volumes of water, one through an emitter yielding large droplets and one yielding small droplets, will result in the former volume having a smaller surface area on which evaporation can occur. For very small drops, it can be shown that even a slight wind can keep the drop suspended long enough that it will evaporate before it makes contact with the ground (Inoue, 1963 in Solomon, Zoldoske and Oliphant, 1996). Figure 5.2 illustrates the influence that the droplet size has on evaporation under windless conditions.

The most striking observation from the study conducted by Edling (1985) is the rapid decrease in evaporation with the increase in droplet diameter. In all cases the 0,6 mm diameter droplet had a predicted evaporation which was one-forth to one-third that of the 0,3 mm diameter droplet evaporation. The 0,9 mm diameter droplet evaporation was about one-half of the 0,6 mm droplet evaporation. Evaporation decrease of about 70% occurred from the 0,9 to the 1,2 mm diameter droplet size.

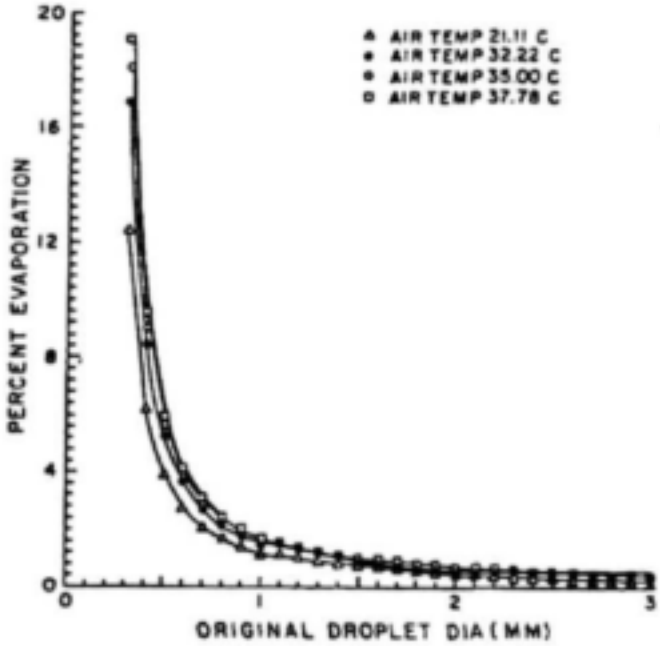


Figure 5.2: Evaporation vs. droplet diameter, no wind (Edling, 1985)

The length of time that a droplet is in the air has a considerable effect on evaporation. This is of particular importance in this project since the impact sprinklers apply water to the field at a height of 3 m, and the Floppy sprinkler from an elevation of 4 m. The water is provided with a trajectory above the horizontal plane that further elevates the height from which the droplet must descend. An important consideration is that the height of application decreases during the growing season as the dense crop canopy of the sugarcane ascends. The initial crop height is equal to the ground level, yet before harvest the crop canopy height approaches three meters. Figure 5.3 provides valuable insight into the influence of nozzle elevation on evaporation under varying wind speeds.

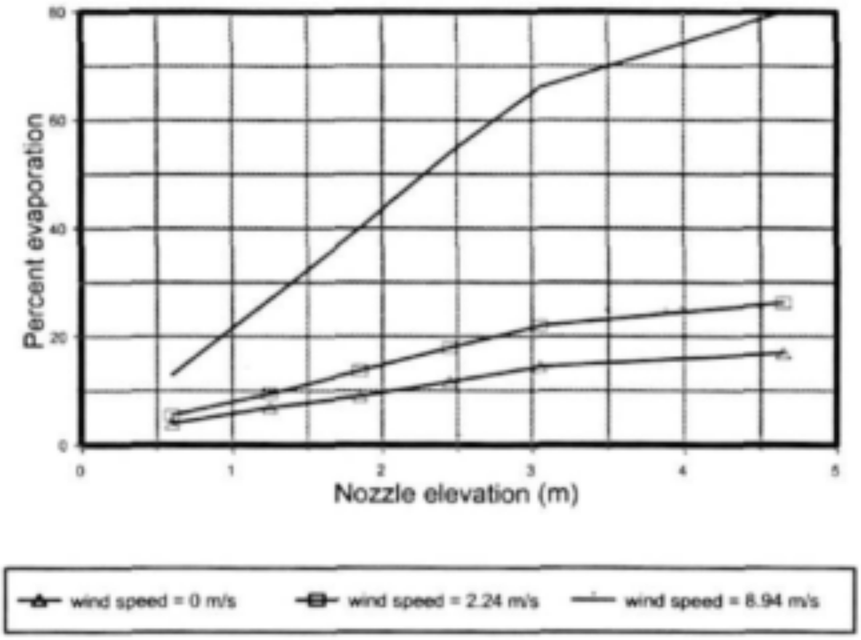


Figure 5.3: Evaporation vs. nozzle elevation, droplet diameter = 0.3 mm (from Edling, 1985)

The ARC-Institute for Agricultural Engineering performed the initial droplet size determination tests in the Irrigation Laboratory at Silverton. Water sensitive paper was placed horizontally on the Sprinkler Test Bench and the three sprinklers were allowed to move individually over the paper. The water sensitive paper was then examined under a microscope to determine the Volumetric Mean Diameter (VMD) for the droplets at various distances from the sprinkler. The trends in the VMD as a function of distance from the three sprinklers were not similar to the theoretical curves shown in Figure 5.6. Figure 5.6 shows that the predicted droplet sizes increase in magnitude with distance from the sprinkler. The curves obtained from the trials were irregular showing no definite relationship between VMD and distance. The results for the impact and Floppy sprinklers, however, showed that for the sprinklers the VMD are, apart from a few outliers, in the interval range between 0.3 and 0.4 mm. This indicates that the three sprinklers produce very similar droplet sizes, and that they will be influenced to a similar degree by evaporation.

The order of magnitude of the sprinkler droplets was acceptable, but the irregular trend did not provide sufficient confidence in the results. It was decided to enter into a second series of droplet size determination tests, which were performed by Philpott (1999). Philpott utilised a Malvern laser optical measuring equipment with a 1 000 mm focal length lens. Impact sprinkler A and the Floppy sprinkler were evaluated to determine the particle size distribution. It was assumed that the two impact sprinklers would produce similar droplet sizes due to the sprinklers operating with the same size nozzle and at the same pressure. The droplet size for the impact sprinkler increases in diameter up to nine metres from the sprinkler, and then decreases in diameter with the trend becoming irregular. Figure 5.4 indicates that the particle size increases to approximately 0.75 mm, and the initial progression of the curve up to nine metres agrees with theory, similar to the curves in Figure 5.6.

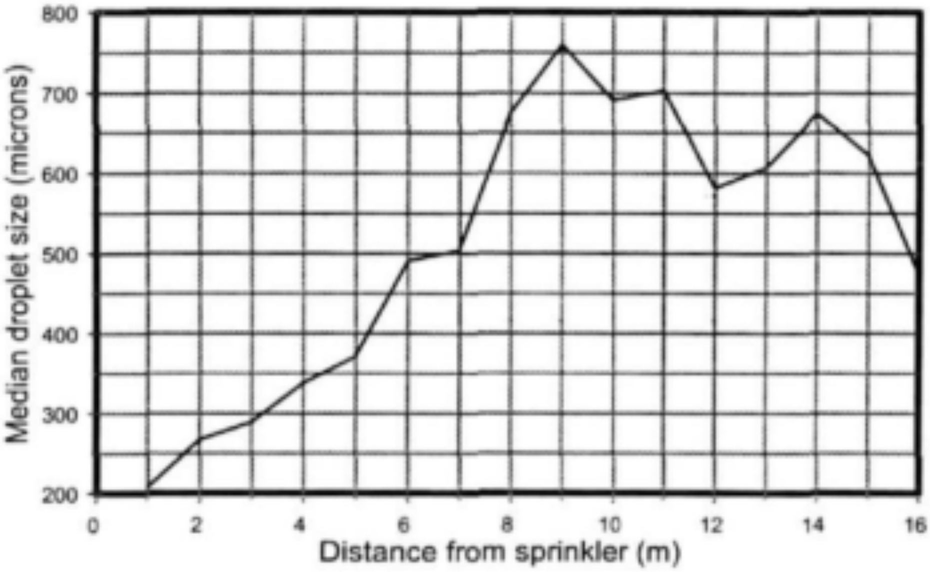


Figure 5.4: Particle size distribution curve with distance from the sprinkler for the impact sprinkler A (Philpott, 1999)

The results for the Floppy sprinkler suggested that the true distribution does not fit the model utilised by the laser in a satisfactory manner. The probable reason for the error can be attributed to the droplets of water splashing onto the lens, and too little diffraction data being captured since insufficient droplets passed through the laser beam. The results from the tests on the Floppy sprinkler were generally disappointing since insufficient data was obtained to plot a graph. The data that was obtained indicated that the droplet size formed by the Floppy sprinkler is in the range from approximately 0.43 mm to 0.925 mm.

The results obtained from the water sensitive paper and laser tests are not in agreement. The droplet sizes recorded in the water sensitive paper tests are smaller than those in the laser tests, however both tests suggest that the drops formed by the two sprinklers are similar in size. Because of this it is assumed that the differences achieved in the application efficiencies can be attributed predominantly to the formation of a microclimate, and not to a difference in droplet sizes formed. This conclusion is supported by the results of the microclimate formation tests where impact sprinklers were evaluated simultaneously on permanent and dragline layouts. The same droplet sizes were formed in each case, but the permanent configuration achieved significantly higher application efficiencies than the semi-permanent or dragline layout due to a high relative humidity environment being formed around the sprinkler system. Designers must consider carefully the losses occurring in a semi-permanent system when designing the system. A dragline system cannot be designed as though its application is similar to a permanent system, but must be designed to compensate for the actual losses that occur. CU remains an important parameter for selecting a suitable sprinkler, but it should be reviewed in conjunction with the application efficiency of the system.

Sprinklers may apply effluent water for waste disposal and/or to stretch water resources. Depending on its source and treatment level, effluent water may contain a variety of obnoxious constituents, which must be confined to the application site. A drops size determines its wind drift, and for effluent systems wind drift means both water loss and the undesirable off-site application of constituents (Addink, Keller, Pair, Sneed and Wolfe, 1980 in Solomon, Zoldoske and Oliphant, 1996).

Irrigated soils without a crop canopy to intercept droplets impacting the surface are subject to structural degradation and sealing. The thin layer of reoriented and/or consolidated soil can decrease infiltration and thus promote runoff and erosion (Ellison, 1947). The impact energy of a falling droplet is one-half the product of mass and velocity squared. Larger drops therefore strike the soil with greater kinetic energy than small drops. Larger droplet diameters (Levine, 1952) and high velocities (Ellison and Slater, 1945) can therefore contribute to decreased infiltration rates.

Where sprinklers with larger nozzles or emitters are utilised crusting of the soil surface will be more significant than with smaller nozzles during the initial stages of crop growth due to the kinetic energy with which the larger droplets make contact with the soil surface. The benefits of larger droplets must however be considered in conjunction with this since the crusting effect can be reduced by a tillage practice.

5.3 Wind

As has been introduced in section 4.2.2 distribution patterns of irrigation applications are affected by wind. Irrigation systems are often designed without adequate consideration of wind, resulting in sub-optimal performance of the system.

Vories and Bernuth (1986) investigated the effects of wind on the maximum radii of throw. Figure 5.5 shows the maximum predicted upwind, downwind and crosswind radii for each of the wind speeds in the test. The figure refers only to the maximum radii and not to the distribution of water along the radius.

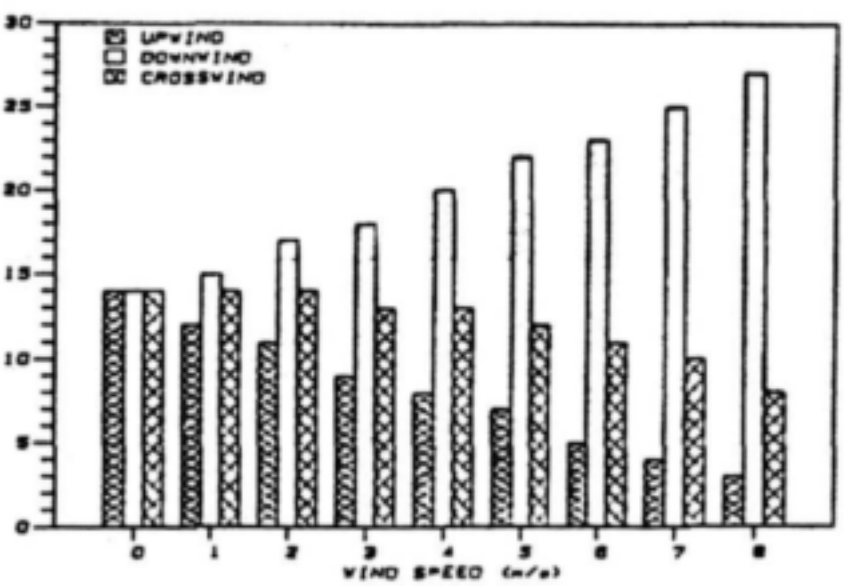


Figure 5.5: Predicted relationship between maximum throw radii and wind speed for a 3,97 mm nozzle of 400 kPa (Vories and Bernuth, 1986)

Further tests by Vories and Bernuth (1986), shown in Table 5.3, utilising four nozzle sizes and several spacings resulted that at each wind speed the CU increased as the nozzle size increased. The only exception was with the largest nozzle which had the lowest CU of the four nozzle sizes at low wind speeds, but at the highest wind speed the largest nozzle had the highest CU value. In Table 5.3 rectangular spacing was compared to triangular for the 3,97 mm nozzle at 400 kPa for varying wind speeds.

Table 5.3: CU values for rectangular and triangular spacing patterns at various wind speeds (from Vories and von Bernuth, 1986)

Wind speed at 2 m, m/s	Christiansen's Coefficient of Uniformity, %							
	Spacing, metres							
	12 x 12		12 x 15		12 x 18		18 x 18	
	Rect.	Tri.	Rect.	Tri.	Rect.	Tri.	Rect.	Tri.
0	91	93	84	86	86	87	82	78
1	92	93	84	86	86	87	82	77
2	92	92	84	85	86	86	81	76
3	92	92	82	83	84	84	79	75
4	91	92	81	82	81	82	77	73
5	91	92	80	80	79	79	74	70
6	89	91	78	79	76	76	71	66
7	89	90	76	77	73	73	69	63
8	86	88	75	76	70	70	66	60

For the traditional spacing and nozzle sizes modelled, an orientation in which the wind blows generally parallel to the short spacing is recommended (Vories and von Bernuth, 1986). Winds blowing perpendicular to the short spacing appear to cause some portions of the field to be very wet, while other portions are too dry. Those wet and dry areas result in lower coefficients of uniformity, but more importantly, they can cause a decrease in production. This design alternative is however not always feasible (Scott, 1998). Other modifications which have been suggested are to lower the nozzles, to not irrigate in high wind conditions or to introduce a closer spacing of sprinklers (Edling, 1985).

The most important factor to consider when analysing the effect of wind is the pressure in relation to the nozzle diameter. This affects the break up of water into droplets and the higher the ratio, the smaller the average droplet size, and the more these droplets will be affected by wind (Scott, 1998). The nozzle selection, operating pressure and sprinkler spacing should therefore be designed to accommodate normal wind conditions.

5.4 Pressure

Pressure variation is probably the most significant variable affecting irrigation uniformity (Crosby, 1997). Sprinkler systems operating at lower pressures have received attention in recent years because of rising energy costs. For an established system, however, a lower pressure usually means larger droplets and a non-uniform distribution pattern (Hills and Gu, 1989). Such patterns lead to poor system application efficiencies. Hills, Gu and Wallender (1987) have shown that this efficiency can be improved through operation of the system with an oscillating pressure centered around a relatively low mean value. Dadiao and Wallender (1985) have shown that by inducing turbulence, non-circular nozzles can also be effective in low pressure operation, yielding acceptable distribution patterns. Hills and Gu (1989) determined the volume mean diameters at specific distances from the sprinkler, averaged from three different runs. The results are presented in Figure 5.6.

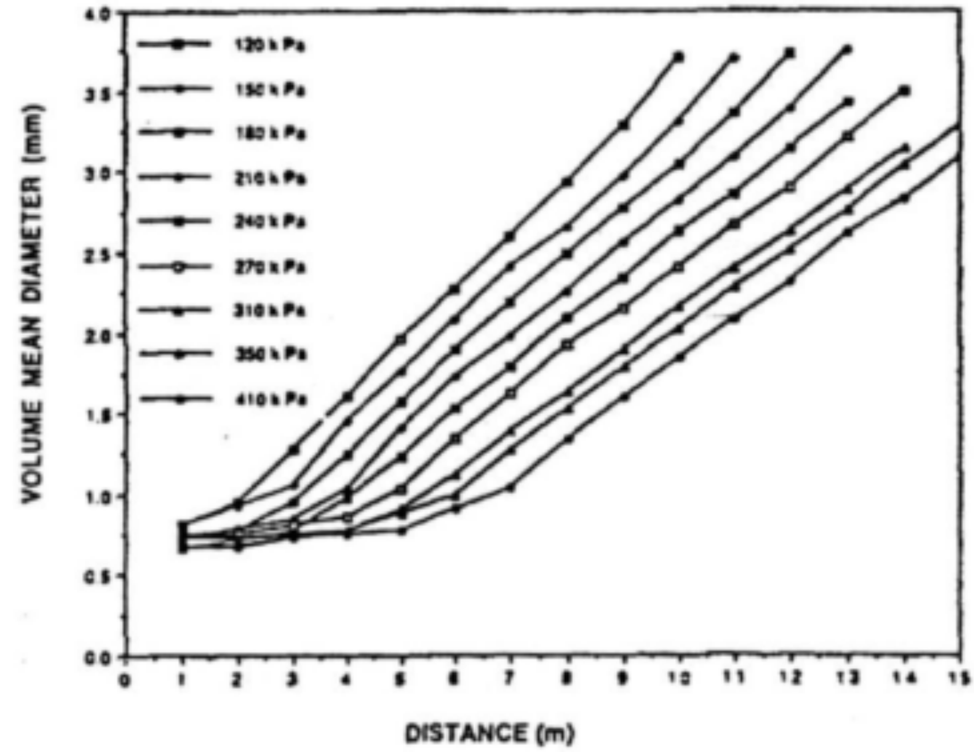


Figure 5.6: Volume means droplet diameters (mm) as a function of distance and pressure for a 4,0 mm circular nozzle (Hills and Gu, 1989)

It is evident that the smaller sizes generally occurred at the higher pressures and are located nearer to the sprinkler. Conversely the larger size droplets were formed at the lower pressures and were located further from the sprinklers. The influence of droplet size on losses has already been discussed and the indirect role that the operating

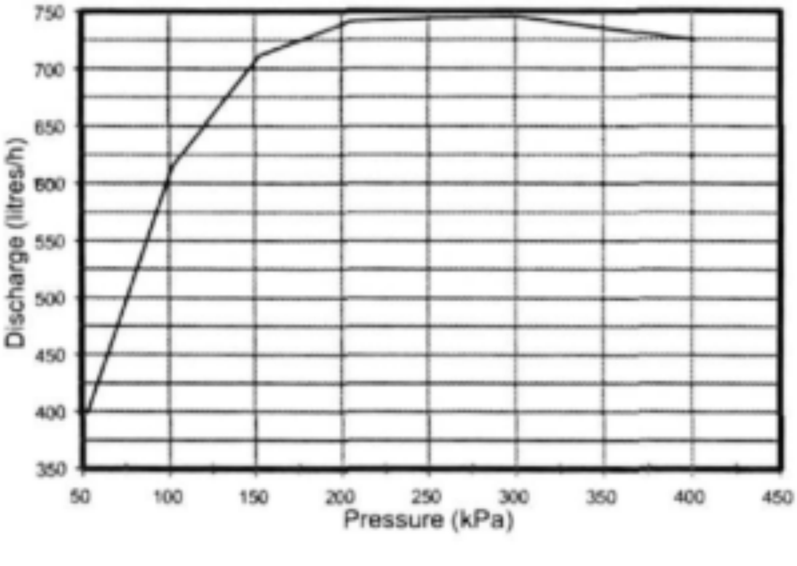


Figure 5.7: Delivery-pressure relationship for the Floppy sprinkler (from laboratory results)

pressure plays in determining the application efficiency is therefore significant. Because of the flow regulator in each Floppy sprinkler the sprinkler is less sensitive to pressure variations than the impact sprinklers are. Figure 5.7 shows the relationship of emitter delivery to the operating pressure for the Floppy sprinkler. The Floppy sprinkler operates at a lower pressure than conventional impact sprinklers, providing a relatively constant delivery for pressures above 200 kPa.

The following two figures, Figures 5.8 and 5.9, indicate the sensitivity of the two impact sprinklers to pressure. The values were obtained from the laboratory results on the Sprinkler Test Bench at ARC-Institute for Agricultural Engineering. Although values of CU have typically been higher in-field than in the laboratory a similar relationship is experienced in-field.

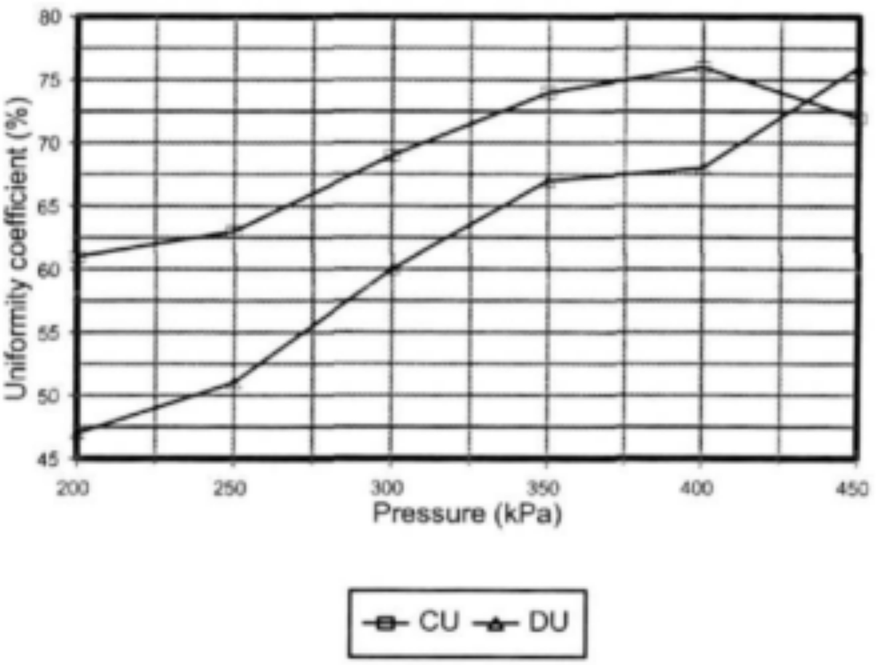


Figure 5.8: Relationship of CU and DU to operating pressure of impact sprinkler A (from laboratory results)

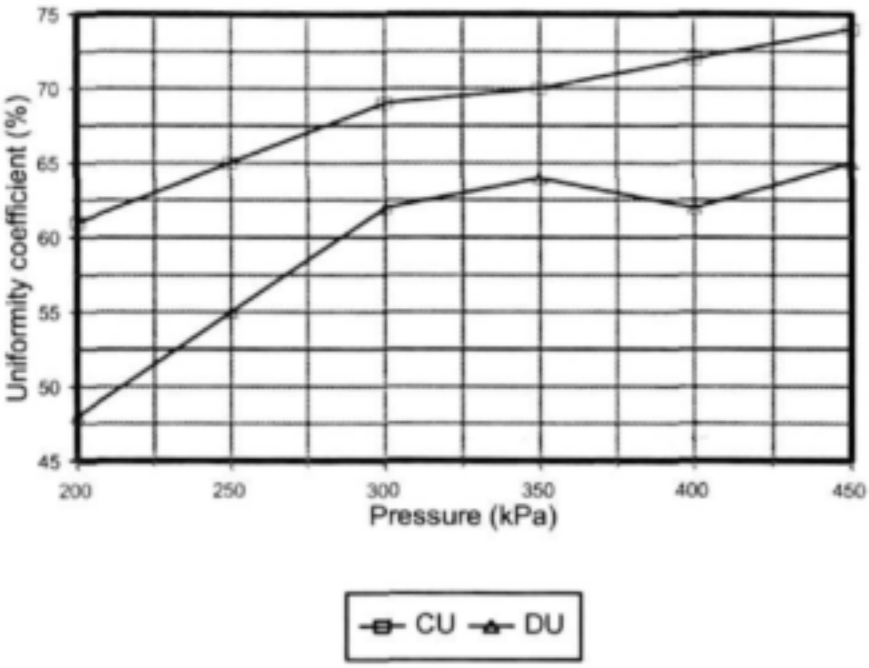


Figure 5.9: Relationship of CU and DU to operating pressure of impact sprinkler B (from laboratory results)

The dependence of CU on pressure is similar for the two impact sprinklers, with impact sprinkler A generally achieving slightly higher values. CU increases with pressure, but when the pressure exceeds 350 kPa excessive breakup of the water trajectory results in smaller water droplets and therefore increased wind drift and evaporation losses. Very similar results are experienced for DU values. The implication of these graphs is that the farmer and labourers must ensure that operating pressures equal design pressures. Operating too many irrigation blocks simultaneously or having infrequent maintenance of leaks, blockages, nozzle wear and pumps can detrimentally influence the operating pressure.

6. COST ANALYSIS

Although the efficiency and profitability of a farming enterprise is dependent on efficient water utilisation the farming business must be viewed holistically and irrigation systems that are economically appropriate must be selected. A semi-permanent system typically has considerably lower capital costs than permanent or mechanised systems. The labour, maintenance, life expectancy, pumping costs and water tariff are inter-dependent variables that must be considered in conjunction with the capital cost to determine the true cost of the system.

The cost analysis of the impact and Floppy systems are summarised in Table 6.1. The two systems were evaluated based on the assumption of a 10% inflation rate and 18% interest rate over a 20-year period. The inflation rate of 10% and the interest rate of 18% were used after personal communication with economists. Present values of costs (PV) were calculated for the various components of each system, and the total PV for the impact and Floppy systems were determined. The PV takes the inflation effect over the 20 years into account. Obtained future values (FV_{20}) were then discounted at 18% per annum to give the worth of each option at the beginning of the venture. The total PV therefore indicates the required expenditure on each system if the total investment has to be made at project initiation. The annual running cost per project is the sum of the labour, pump, maintenance, water costs and depreciation, after compensation for inflation.

Estimations by Pretorius (1998) and Combrinck (1998) were that the Floppy system would have a life-span of 20 years, and the dragline 10 years. For comparison purposes the dragline system was analysed with two consecutive identical systems. Maintenance costs for the dragline system were also calculated over a 20 year period, based on the inflation-adjusted cost of replacing system parts at required intervals. This included yearly nozzle, 4-yearly hose, 5-yearly sprinkler, and 10-yearly standpipe and lateral pipe replacements. A linear depreciation, with adjustment for inflation, was utilised to calculate the annual depreciation cost of the Floppy system.

Table 6.1: Summary of the cost study on the Floppy sprinkler and dragline impact sprinkler systems per hectare

Cost item		Permanent-set Floppy sprinkler	Dragline Impact sprinkler
Capital items			
	Installation cost	R 1 800	R 1 000
	In-field equipment	R10 100	R 5 500
Operational items			
	Labour	R 2 524	R10 097
	Pumping cost	R 7 831	R 9 792
	Maintenance	R 2 746	R 2 791
	Water	R 6 792	R 8 494
Operational cost			
	Running cost	R19 893	R31 174
	Capital cost	R11 900	R 6 500
Total present value		R31 793	R37 674

The capital cost of the permanent system is higher than the dragline system. This is due to the additional pipes and fittings for the Floppy system. The Floppy system is more expensive to install due to the additional pipes and the burying of laterals. In determining the labour costs Pretorius (1998) stated that for the Floppy system one labourer can manage 100 ha of cultivated land. Dragline systems require regular moving of standpipes and each labourer is allocated 25 ha. This ascribes for the higher labour cost of the dragline sprinkler system.

The application efficiency of water was taken to be 88.5% and 70.8% for the Floppy and impact sprinkler systems respectively. These values are representative of the efficiencies achieved during a 24-hour irrigation day cycle for the respective sprinklers as it was measured. By utilising the 18-hour irrigation cycle application efficiency values of 87.8% and 65.8% for the Floppy and impact sprinklers respectively, the total present value of the system increases to R31 930 and R39 049. These values of application efficiency are the average values obtained from the entire data set, during all four test time periods, of the Silverton trials. The benefit of irrigating at night as well as during the day therefore has large implications on the total cost of an irrigation system. The pressure head provided at the in-field block was taken to be 45 m for the impact sprinkler test block and 38 m for the Floppy sprinkler block. The lower design inlet pressure for the Floppy is due to the lower operating pressure of the Floppy sprinkler.

The pumping cost was taken to be 18 c/kWh, and the water cost at 2.04 c per cubic metre. The yearly irrigation water required was taken to be the annual crop requirement less the mean annual rainfall. The generally accepted gross annual crop water requirement is approximately 2 000mm, and the mean annual rainfall is approximately 700mm. The annual irrigation requirement is therefore approximately 1 300mm. The present value operational cost is the summation of the annual labour, pumping, maintenance and water costs. The present value of the Floppy system running cost is almost R6 000 less than that of the dragline impact sprinkler system operating cost.

7. CONCLUSIONS AND RECOMMENDATIONS

The uniformity parameters achieved by the three systems are generally acceptable, and in many instances very good for in-field results. The CU and DU vary with the system selected and with relative humidity. The uniformity indicators do not vary significantly through the progress of the day, or with the varying wind speeds experienced at Silverton. The Floppy sprinkler system achieved a higher mean CU and DU for the Silverton trials, and exhibited a smaller range of data. The statistical analysis yielded that the Floppy sprinkler on a permanent layout performed significantly better than the impact sprinklers for the trails at Silverton. Solomon (1990; 1988a) showed the influence of CU on potential sugarcane yield and the relationship between DU and total farm cost in section 4.12. Additional initial investment required to achieve a higher system distribution uniformity is justified in the long term due to lower system running costs.

Pressure variation is probably the most significant variable affecting irrigation uniformity. Figures 5.7 and 5.8 show the relationship of CU and DU to operating pressure of the impact sprinklers. Farm managers must monitor irrigation block inlet pressures on a regular basis. Farm labourers should be equipped with correctly calibrated pressure gauges and trained in the use of these instruments to ensure optimal operation of sprinkler emitters. A common problem on large farms or estates is that too many irrigation blocks are operated simultaneously, thus reducing the inlet pressure to the operational blocks.

Regular maintenance is essential if the systems are to operate as designed. The dragline impact sprinkler system especially requires a structured maintenance programme due to nozzle wear, hose degradation and general damage due to the continual moving of the standpipe positions. Due to the nature of the connections in the Floppy system competent contractors should be selected for the installation of the system. Subsurface installation of laterals should be of a high quality to ensure that unnecessary leaks are avoided. When selecting the 20 year lifetime of a Floppy system it was deemed necessary to utilise class 6 pipes to limit pipe bursts that may occur with the cheaper class 3 pipes.

The scheduling coefficient determination yielded mean values of 1,5; 1,8 and 1,3 for impact sprinkler A, impact sprinkler B and the Floppy system respectively. These values indicate that the region with the lowest application was least critical in the case of the Floppy sprinkler on a permanent layout, and less critical for the impact sprinkler A when compared to the impact sprinkler B. It would not be advised to utilise the scheduling coefficient as a multiplier to determine stand times as is the practice in turf irrigation. The parameter is more important for agricultural irrigation an indicator of how low the application is in the most critical portion of the field.

When reviewing published evaporation studies in Table 4.10 the differences in definitions of evaporation and wind drift losses becomes evident. The application efficiency is the ratio between the volume of water reaching the crop canopy, and the amount of water exiting the emitter. The percentage of the volume of water lost during irrigation is attributed to the combination of wind drift and spray evaporation. The nomograph developed by Frost and Schwalen (1955) is a useful tool for estimating losses under various climatic and operating conditions. Reasons why the results achieved in the present evaluations did not always concur with the evaporation losses from the nomograph are that nozzle elevation is not a variable on the nomograph, and the evaluations were performed at a greater height than the Frost and Schwalen (1955) trials. A further motivation is that the trials performed by Frost and Schwalen (1955) were tested for a permanent system while the present impact sprinkler evaluations were done on dragline systems, since this is how the sprinklers are operated in practice.

The application efficiency results for the evaluations at Silverton and Komatipoort show that the Floppy sprinkler operating on a permanent layout achieves significantly higher values than either of the impact sprinklers on a dragline system. This was validated by the statistical analysis performed by Müller (1999). The application efficiency results in Figure 4.4 and 4.5 show similar trends for the plot of application efficiency as a function of time of day, and for the regression curve as a function of the square of radiation. The analysis of application efficiency for the trials at Silverton indicate that a prediction model of application efficiency as a function of the square of radiation could be considered. An important consideration emanating from this study is that the application efficiency should be considered in conjunction with CU when selecting an appropriate irrigation sprinkler.

The size of droplet formed by a sprinkler has an influence on losses occurring in the system. Smaller droplets have a larger relative surface area, for a given volume, on which evaporation can take place and are affected to a greater extent by wind. As the operating pressure in an impact sprinkler system increases, so the water trajectory is dispersed into smaller droplets, but the CU generally increases with increasing pressure. A compromise must be reached to optimise the system with a satisfactory coefficient of uniformity, but limiting excessive wind drift losses. The spacing of the sprinklers must also be optimised to achieve a satisfactory CU but limit the capital cost of the system. As the spacing increases, the CU generally decreases, and wind plays a more dominant role in determining the CU. An orientation in which the prevailing wind direction blows parallel to the short spacing is recommended where feasible. The most important factor to consider when analysing the effect of wind is the pressure in relation to the nozzle diameter. This affects the break up of water into droplets and the higher the ratio, the smaller the average droplet size, and the more these droplets will be affected by wind. The nozzle selection operating pressure and sprinkler spacing should therefore be designed for a specific region to accommodate normal wind conditions.

The losses occurring in an overhead irrigation system are influenced by the formation of a microclimate by operating sprinklers in a permanent configuration. The microclimate increases relative humidity and reduces the atmospheric saturation deficit. Trials on impact sprinkler permanent and dragline systems at Silverton indicated that the mean application efficiency for the permanent system is 33% greater than the mean value for the dragline system. This indicates that a permanent impact sprinkler system would be competitive in performance with the Floppy sprinkler system. The Floppy sprinkler as it utilised at present in practice is superior, in terms of application efficiency, to the impact sprinklers utilised on a dragline system. This is due predominantly to the formation of a microclimate, and the resulting reduced atmospheric demand within the irrigation block. Indications are that droplet size is not a major factor in influencing the application efficiency for the sprinklers evaluated since the microclimate formation trials showed considerably different efficiencies with the same sprinkler. The only difference was the system layouts, one being permanent and one a dragline system.

The capital cost of a permanent impact sprinkler system is relatively high, although some farmers do utilise this layout. If the cost of a permanent impact sprinkler system could be reduced by increasing the spacing of laterals and sprinklers, the impact and Floppy permanent systems would be very competitive, both in terms of total cost, and in efficiency of applying water to the crop. By utilising the permanent impact sprinkler layout the life expectancy of the system would be increased since the wear on the system would be reduced due to the cessation of regular standpipe moving. Yearly replacement of the sprinkler nozzles should, however, remain part of the maintenance programme. Permanent systems have the advantage that increased automisation of the system is possible in the future, which is becoming more viable with increased labour wage regulations.

The yield of sugar generally expected is one ton for every nett 9 mm of water applied to the ground. The expected yield of sugarcane is therefore a function of the application efficiency of the irrigation system. In this study, the two systems that are generally used in the Lowveld area, the dragline impact sprinkler system and the permanent Floppy system confirmed the importance of application efficiencies. It is, however, essential to note that the dragline impact sprinkler system and the permanent Floppy system are not the only means of irrigating sugar cane in South Africa. Drip irrigation, both above and below the ground, as well as mechanised systems such as centre pivots are widely utilised and their application efficiencies must also be verified.

The capital cost of a system cannot be isolated and utilised to determine the cost implication of a system. The capital cost was therefore reviewed in conjunction with the labour, maintenance, life expectancy, pumping costs and water tariff. It was determined that the running cost of the permanent Floppy system is less than that of the dragline impact sprinkler system. This is due to lower labour costs and a reduced pumping head since the Floppy system is operating at a lower pressure. Less pumping hours result since the Floppy system applies the water more efficiently, and because the application efficiency is higher for the Floppy system, less water is utilised.

This set of evaluations are the first comprehensive scientifically performed trials that have been performed on the permanent layout Floppy sprinkler system. The Floppy system achieves similar uniformities to the current standard method of irrigating sugarcane, namely the dragline impact sprinkler system, and achieves significantly higher application efficiencies. A dominant reason for the higher efficiency is the formation of a microclimate in the irrigation block due to the permanent layout. This phenomenon increases the relative humidity and reduces the saturation deficit resulting in a decline in evaporation losses. The lower operating pressure and the incorporation of the flow controller are advantages of the Floppy system. Although the system has a relatively high capital cost, the running cost of the system is lower than the dragline impact sprinkler system.

7.1 Further Evaluations

A need for further investigation is to determine the effectiveness of irrigating with large applications relatively infrequently, for example a 12 hour stand time on an eight day cycle. Management trends shifting to two six hour stands during a seven day cycle would be more easily facilitated with permanent or mechanised irrigation systems than semi-permanent systems.

A further aspect still requiring analysis is the role of application rate in losses occurring at the emitter. The role of microclimate formation is significant, but the possibility that it is compounded by losses being a function of application depth applied must be reviewed. The effect of low application volumes on a plant should also be reviewed.

The positive results of the permanent impact sprinkler system are somewhat diminished by the inhibitive cost of such a system. By utilising appropriate sprinklers with large wetted diameters the spacing between sprinklers can be enlarged and the capital cost reduced. Evaluations on these systems would determine if the efficiencies and uniformities of these systems are acceptable and competitive with other irrigation systems. The spacing of laterals and sprinklers, as well as the performance of a particular sprinkler system in different regions should be studied.

8. ACKNOWLEDGEMENTS

The joint funding of this project by the Water Research Commission and the National Department of Agriculture is sincerely appreciated. The members of the Steering Committee are thanked for their significant contributions to the project. The Steering Committee comprised, in alphabetical order, of the following members:

Dr GR Backeberg	:	Water Research Commission
Mr S Bunton	:	ARC-Institute for Agricultural Engineering
Mr J Hiemstra	:	Floppy Sprinklers (Pty) Ltd
Mr G Kraaij	:	House of Irrigation (Pty) Ltd
Mr L Phelan	:	Rain Bird International (Pty) Ltd
Mr A Pretorius	:	Transvaal Sugar Limited
Mr FB Reinders	:	ARC-Institute for Agricultural Engineering
Mr GB Simpson	:	ARC-Institute for Agricultural Engineering
Mr CM Stimie	:	ARC-Institute for Agricultural Engineering
Mr C Theron	:	Floppy Sprinklers (Pty) Ltd
Mr AT van Coller	:	National Department of Agriculture
Mr DS van der Merwe	:	Water Research Commission (Chairman of committee)
Mr Morné van Zyl	:	ARC-Institute for Agricultural Engineering

Transvaal Sugar Limited are thanked for their assistance in the economic study, and for the utilisation of their farm at Komatidraai for evaluations. The role of Heléne Müller, of the ARC-Agrimetrics Institute, in performing the statistical analysis on the evaluation results is appreciated. Mike Philpott of ARC-Institute for Soil, Climate and Water is thanked for performing the droplet size tests. Lindie Beyers of ARC-Institute for Agricultural Engineering is thanked for her aid in the cost analysis.

9. REFERENCES

1. American Society of Agricultural Engineers, 1998. ASAE Standards 1998. American Society of Agricultural Engineers, St. Joseph, MI 49085. pp 822 - 824.

2. Anon., 1993. Genstat 5. Committee of the Statistics Department, Rothamsted Experimental Station, Claredon Press, Oxford.

3. ARC-Institute for Agricultural Engineering, 1998. In-field Evaluations of the Performance of Two Types of Irrigation Emitters executed on behalf of the Water Research Commission. Water Research Commission, Republic of South Africa.

4. Christiansen, J.E. 1941. The Uniformity of Application of Water by Sprinkler Systems. Agricultural Engineering. pp 89 - 92.

5. Christiansen, J.E. 1942. Irrigation by sprinkling. University of California, Agricultural Experiment Station. B-670, Berkley, CA 94720, pp. 110 - 116.

6. Combrinck, N. 1998. Transvaal Sugar Limited, Mpumalanga, Republic of South Africa. Personal communication.

7. Crosby, C.P. 1997. Rapid Determination of the Sensitivity of Sprinkler Irrigation Distribution Uniformity to Various Operational Discrepancies. Irrigation 2001. 11th Bi-Annual Congress of the South African Irrigation Institute, Blyderiver, Mpumalanga, Republic of South Africa.

8. Crosby, C.T. 1998. Personal Communication.

9. Dadiao, C. and Wallender, W.W. 1985. Droplet Size Distribution and Water Application with Low Pressure Sprinklers. Transactions of the ASAE. Vol. 28 (2): 511 - 516.

10. Edling, R.J. 1985. Kinetic Energy, Evaporation and Wind Drift of Droplet from Low Pressure Irrigation Nozzles. Transactions of the ASAE. Vol. 28 (5); 1543 - 1550.

11. Ellison, W.D. 1947. Soil Erosion studies - Part III. Agricultural Engineering. Vol. 28 (6): 245 - 248.

12. Ellison, W.D. and Slater, C.S. 1945. Factors that affect surface sealing and infiltration of exposed soil surfaces. Agricultural Engineering. Vol. 26 (3): 156 - 157, 162.

13. Frost, K.R. and Schwalen, H.C. 1955. Sprinkler Evaporation Losses. Agricultural Engineering. 36 (8): 526 - 528.

14. George, T.J. 1955. Evaporation from irrigation sprinkler sprays as determined by an electrical conductivity method. Unpublished M.S. thesis. University of California, Davis, CA 95616.

15. Herrmann, M. 1997. Bayer Ag. Geschäftsbereich, Anorganische Industrieprodukte, Marketing Silicone, D51368 Leverkusen. Facsimile number 17 - 01.

16. Hills, D.J. Gu, Y. and Wallender, W.W. 1987. Sprinkler Uniformity for Oscillating Low Water pressure. Transactions of the ASAE. Vol. 30 (3): 729 - 734.

17. Hills, D.J. and Gu, Y. 1989. Sprinkler Volume Mean Droplet Diameter as a Function of Pressure. Transactions of the ASAE. Vol. 32 (2): 471 - 476.

18. Keller, J. and Bliesner, R.D. 1990. Set Sprinkler Uniformity and Efficiency. Sprinkle and Trickle Irrigation. Chapman and Hall, New York.

19. Kinzer, G.D. and Gunn, R. 1951. The evaporation, temperature, and thermal relaxation-time of free falling water drops. Journal of Meteorology 8(2): 71 - 83.

20. Koegelenberg, F. 1999. ARC-Institute for Agricultural Engineering, Stellenbosch, Republic of South Africa. Personal Communication.

21. Kohl, K.D., Kohl, R.A. and de Boer, D.W. 1987. Measurement of Low Pressure Sprinkler Evaporation Loss. Transactions of the ASAE, Vol. 30 (4): 1071 - 1074.

22. Kraus, J.H. 1966. Application Efficiency of Sprinkler Irrigation and Its Effect on Microclimate. Transactions of the ASAE. pp 642 - 645.

23. Levine, G. 1952. Effects of irrigation droplet size on infiltration and aggregate breakdown. Agricultural Engineering. Vol. 33 (9): 559 - 560.

24. Longley, T.S. Garvin, P.C. and Stark, J.C. 1983. Wind drift effects on evapotranspiration under low pressure sprinklers. ASAE Paper No. 83-2590, ASAE, St. Joseph, MI 49085.

25. Mather, J.R. 1950. An Investigation of Evaporation from Irrigation Sprays. Agricultural Engineering 31 (7): 345 - 348.

26. Müller, H. 1999. Biometriese Verslag. Statistiese Ontleding - Evaluering van Twee Tipes Emitters. ARC-Agrimetrics Institute, Republic of South Africa.

27. Philpott, M. 1999. ARC-Institute for Soil, Climate and Water, Republic of South Africa. Personal Communication.

28. Pretorius, A. 1998. Transvaal Sugar Limited, Mpumalanga, Republic of South Africa. Personal Communication.

29. Reinders, F.B. 1996. Irrigation Systems: Evaluation and Maintenance. SA Irrigation, Vol. 5 - 7.

30. Robinson, F.E. 1993. Increases in conductivity of irrigation water during irrigation. Agron. J. 65(1): 130.

31. Schreiner, B. 1998. Water Demand Management - An Overview in Water Demand Management Workshop II: 5 - 7. Center for Scientific and Industrial Research, Republic of South Africa.

32. Scott, K. 1997. Designing with Sprinklers, Unpublished literature. ARC-Institute for Agricultural Engineering. Silverton, Republic of South Africa.

33. Scott, K. 1998. The effects of wind on sprinkler irrigation. ARC-Institute for Agricultural Engineering. Republic of South Africa.

34. Seginer, I. 1971. Water Losses during Sprinkling. Transactions of the ASAE. pp 656 - 659.

35. Silva, W.L.C. and James, L.G. 1988a. Modelling Evaporation and Microclimate Changes in Sprinkle Irrigation : I. Model Formulation and Calibration. Transactions of the ASAE, Vol. 31 (5): 1481 - 1486.

36. Silva, W.L.C. and James, L.G. 1988b. Modelling Evaporation and Microclimate Changes in Sprinkle Irrigation: II. Model Assessment and Applications. Transactions of the ASAE, Vol. 31 (5): 1487 - 1493.

37. Solomon, K.H. 1988a. Irrigation Systems and Water Application Efficiencies. Center for Irrigation Technology, California State University, Fresno, California.

38. Solomon, K.H. 1988b. A New Way to View Sprinkler Patterns. Center for Irrigation Technology, California State University, Fresno, California.

39. Solomon, K.H. 1990. Sprinkler Irrigation Uniformity. Center for Irrigation Technology, California State University, Fresno, California.

40. Solomon, K.H, Zoldoske, D.F. and Oliphant, J.C. 1996. Laser Optical Measurement of Sprinkler Drop Sizes. Center for Irrigation Technology, California State University, Fresno, California.

41. Stenburg, Y.A. 1967. Analysis of sprinkler irrigation losses. Journal of the Irrigation and Drainage Division of ASCE. 93(IR4): 111 - 124.

42. Till, M.R. 1957. A method of measuring the evaporation loss from sprinklers. The Journal of the Australian Institute of Agricultural Science. 23(12): 333 - 334.

43. Van der Merwe, F. 1998. Water Demand Management in Irrigation. In Water Demand Management Workshop II: 11 - 14. Center for Scientific and Industrial Research, South Africa.

44. Van der Ryst, C. 1991. Identifisering, Kwantifisering en Beperking van Waterverliese onder Spilpuntbesproeiingstelsels. WRC Report No. 153/1/91. Water Research Commission. Republic of South Africa.

45. Viljoen, P.D. 1997. Sprinkler Irrigation. Irrigation Design Manual. ARC-Institute for Agricultural Engineering, Republic of South Africa.

46. Vink, N. 1998. The economic impact of changes in water policies on agriculture in the Western Cape. SA Irrigation Vol. 20, 2: 3 - 9.

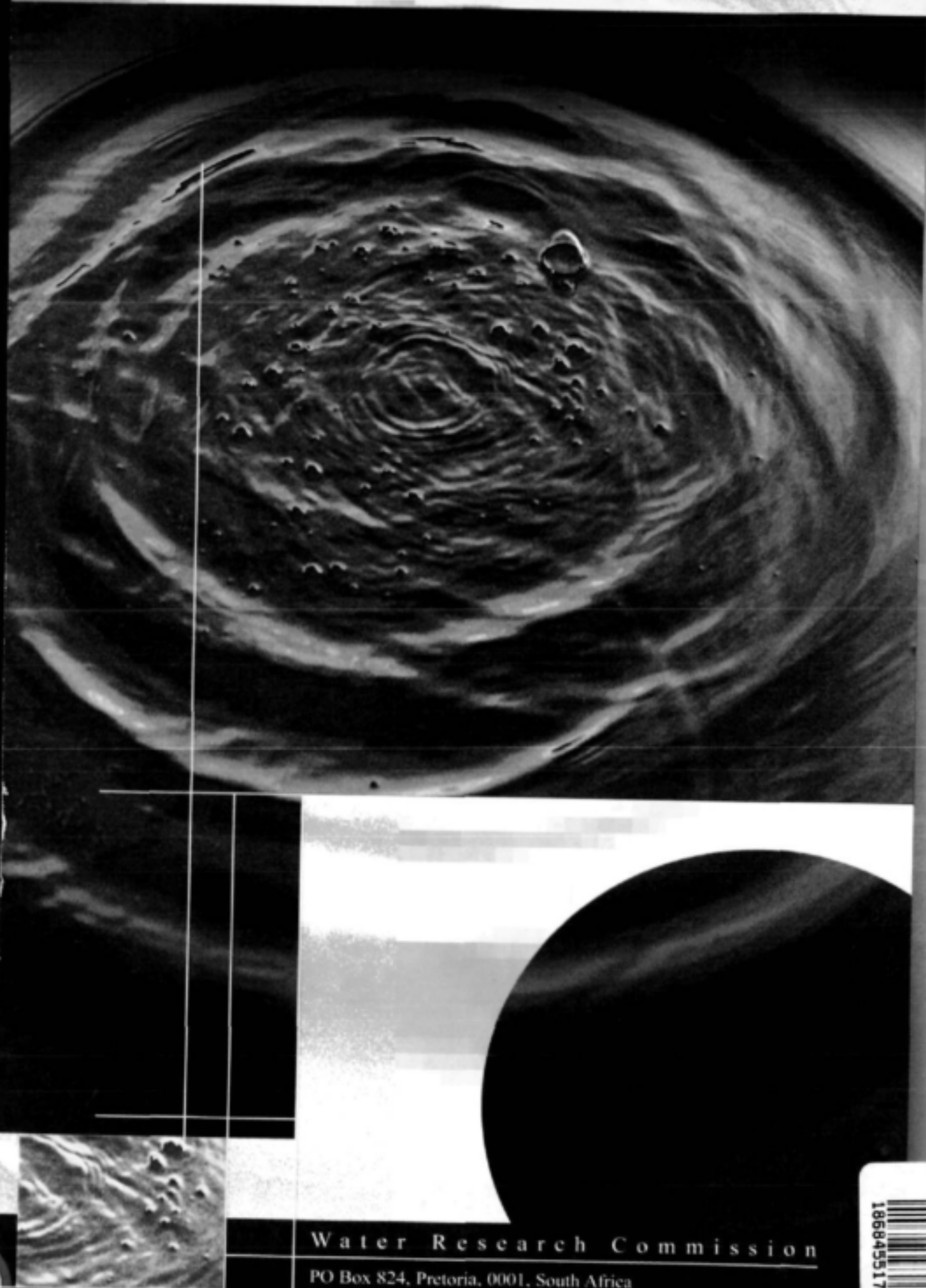
47. Vories, E.D. and Von Bernuth R.D. 1986. Single Nozzle Sprinkler Performance in Wind. Transactions of the ASAE. Vol. 29 (5): 1325 - 1330.

48. Yazar, A. 1984. Evaporation and drift losses from sprinkler irrigation systems under various operating conditions. Agricultural Water Management. 8: 439 - 449.

49. Zoldoske, D.F. and Solomon, K.H. 1988. Coefficient of Uniformity - What it tells us. Center for Irrigation Technology, California State University, Fresno, California.

10. LIST OF FIGURES

11. LIST OF TABLES



Water Research Commission

PO Box 824, Pretoria, 0001, South Africa

Tel: +27 12 330 0340, Fax: +27 12 331 2565

Web: http://www.wrc.org.za