Know-how for Horticulture™

Best practices for irrigation and fertiliser management on sandy soils

Neil Lantzke
Agriculture Western Australia

Project Number: VG98013

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HORTICULTURE AUSTRALIA PROJECT VG98013

BEST PRACTICES FOR IRRIGATION AND FERTILISER MANAGEMENT ON SANDY SOILS

FUNDED BY:

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HORTICULTURE AUSTRALIA PROJECT VG98013

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FUNDING SOURCES

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PURPOSE

To improve sprinkler irrigation and fertiliser management by growers who farm on sandy soils.

PROJECT STAFF

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DATE OF REPORT

March 2003

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MEDIA SUMMARY

Better sprinkler irrigation design and fertiliser management - a winner for vegetable growers and the environment

A three-year research project funded by HAL and the Vegetable Levy on improved irrigation design and fertiliser management of vegetable cropping on sandy soils has just been completed.

A survey of horticultural growers on the Swan Coastal Plain (SCP) showed that only 10 per cent of their sprinkler systems were operating at or above the accepted standard of uniformity. A common design problem of the sprinkler irrigation systems was that sprinklers were spaced too widely for the windy conditions.

Also growers overcompensated for poor irrigation design by over irrigating which required over fertilising because of leaching of fertiliser nutrients. Better irrigation design can improve grower profitability, reduce nutrient losses and increase water use efficiency.

Development Officers Neil Lantzke and Krishan Gupta tested the effect of wind speed on the uniformity of 29 sprinklers, supplied by manufacturers, with different nozzle sizes and combinations of single and double jets. The tests were carried out over a range of wind speeds. The results from the trial will provide sprinkler manufacturers, suppliers and growers with information that will help them select the appropriate sprinkler and spacing under field conditions.

An irrigation system designed optimally taking in to consideration the effect of wind speed will cost more than a poorly designed one. However, it is anticipated that over the life of the irrigation system, the savings accrued from the lower operating costs (pumping water, fertilisers and environmental) of a more uniform system would offset the lower installation cost and higher running cost of poorly designed systems.

The irrigation and nitrogen requirements of cabbage on the sands of the SCP were investigated. The amount of nitrogen and water that the crop requires in each week of its life was determined. This information will help growers reduce fertiliser costs, irrigation and the leaching of nutrients.

A best practice manual for vegetable production on the Swan Coastal Plain has been produced. It contains information that will allow growers to more efficiently apply fertiliser and water to vegetable crops on the sandy soils.

TECHNICAL SUMMARY

The aim of the project was to improve irrigation and fertiliser management of vegetable cropping on sandy soils. The project consisted of three components:

- Testing of the application uniformity of sprinklers over a range of wind speeds
- Irrigation and nitrogen requirements of a summer grown cabbage crop
- Best practices manual for vegetable production on the Swan Coastal Plain

Sprinkler testing

Poor irrigation design and management of vegetable crops on the sandy soils of the Swan Coastal Plain (SCP) have resulted in leaching of costly nutrients, increased pumping costs and reduced crop yield and quality.

Wind speed and direction often distorts the uniformity of sprinkler irrigation but it is rarely considered when selecting the system. Specification data on sprinklers given by manufacturers/suppliers does not include the effect of wind on sprinkler's performance. Uniformity of any sprinkler system depends largely on the combination of sprinkler and nozzle selection, operating pressure and sprinkler spacing. In Perth, wind speeds are high and exceed 16 km/hr, 75 per cent of the time during the main irrigation season.

The effect of wind speed on the uniformity of 29 sprinklers, supplied by manufacturers, with different nozzle sizes and combinations of single and double jets were examined. The tests were carried out over a range of wind speeds. The pattern from a single sprinkler was over-lapped for a range of spacings in a square or rectangular configuration using SPACE Pro software. The results highlight the necessity of proper spacing, lateral orientation and the operation of the system at recommended pressure to achieve acceptable distribution uniformity. The results from the trial will provide sprinkler manufacturers, suppliers and growers with information that will help them select the appropriate spacing for each sprinkler under field conditions. Graphs produced for each sprinkler at common spacings show how the uniformity of the irrigation pattern is affected as wind speed is increased.

An irrigation system designed optimally taking in to consideration the effect of wind speed will cost more than a poorly designed one. However, it is anticipated that over the life of the irrigation system the savings accrued from the lower operating costs (pumping water, fertilisers and environmental) of a more uniform system would offset the lower installation cost of poorly designed systems.

Irrigation and nitrogen requirements of a summer grown cabbage crop

The nitrogen and irrigation requirements of cabbage on a Karrakatta sand were examined using a line source trial. Weekly crop harvests allowed the development of crop factors and optimum nitrogen rates for each week of the crops life. Data is provided on the irrigation and nitrogen required to achieve 99 per cent and 95 per cent of maximum yield.

The percentage of evaporation replacement required increased from 100 per cent in week 2 to 137 per cent in the week prior to harvest. The weekly rate of nitrogen required increased from 31 kg N/ha in week 2 to around 72 kg N/ha from week 5 onwards. A total of 410 kg N/ha/crop was required over the life of the crop for 95 per cent of maximum yield. 570 kg N/ha/crop was required over the life of the crop for 99 per cent of maximum yield.

Lysimeters were installed to allow a water and nutrient balance to be conducted over the life of the crop. At the optimum nitrogen and irrigation rate approximately 70 per cent of the water and 50 per cent of the nitrogen applied was leached past the root zone and collected in the lysimeters. These loss rates demonstrate the poor water and nitrogen use efficiency that is achievable on the coastal plain sands when vegetable crops are watered twice daily with overhead sprinklers and fertiliser is applied weekly.

Best practices manual for vegetable production on the Swan Coastal Plain

The best practice manual provides information on the management of land and water resources in order to:

- Promote and bring about the adoption and continuing development of sustainable horticultural practices.
- Define acceptable management practices to minimise future land use conflict and inform adjacent land users about the likely impacts from horticultural management practices.
- Provide accurate information on horticultural management practices that can be used by government agencies to:
  - assess the environmental risks and social impacts associated with horticultural development;
  - negotiate future changes to management practices with horticultural industries.
- Provide people new to horticulture with guidelines to establish and manage their properties.

1. INTRODUCTION

Introductions to each component of the project are contained within that section of the report:

- Sprinkler testing (Section 2.1).
- Irrigation and nitrogen requirements of a summer grown cabbage crop (Section 3.1).
- Best practices manual for vegetable production on the Swan Coastal Plain (Section 4.1).

2. SPRINKLER TESTING PROGRAM

2.1 Introduction

Sprinkler manufacturers provide specifications on the recommended operating pressure, discharge, radius of throw and uniformity of sprinklers. Uniformity measurements are based on testing conducted indoors. When operated under field conditions wind can greatly distort sprinkler wetting patterns decreasing the uniformity of application. This can lead to decreased water use efficiency, increased leaching of nitrogen fertiliser and detrimental effects on crop yield and quality. There is rarely information available from the manufacturer as to what sprinkler spacings and which configuration (square, rectangle or triangular) would optimise sprinkler uniformity under windy conditions.

A survey of horticultural properties on the Swan Coastal Plain (Western Australia) showed that only 10 per cent of sprinkler irrigation systems operated at the internationally accepted level of uniformity (Milani and Calder, 1990). A major cause of the poor uniformity was that many of the irrigation systems had been designed for still or low wind conditions. The coastal plain experiences strong wind speeds averaging over 16 km/hr for 70 per cent of the time during the main irrigation season (Figure 2.1). The survey showed that improper spacing, orientation (placement of mainline and laterals in relation to wind direction) and lower than recommended operating pressures lead to poor uniformity.

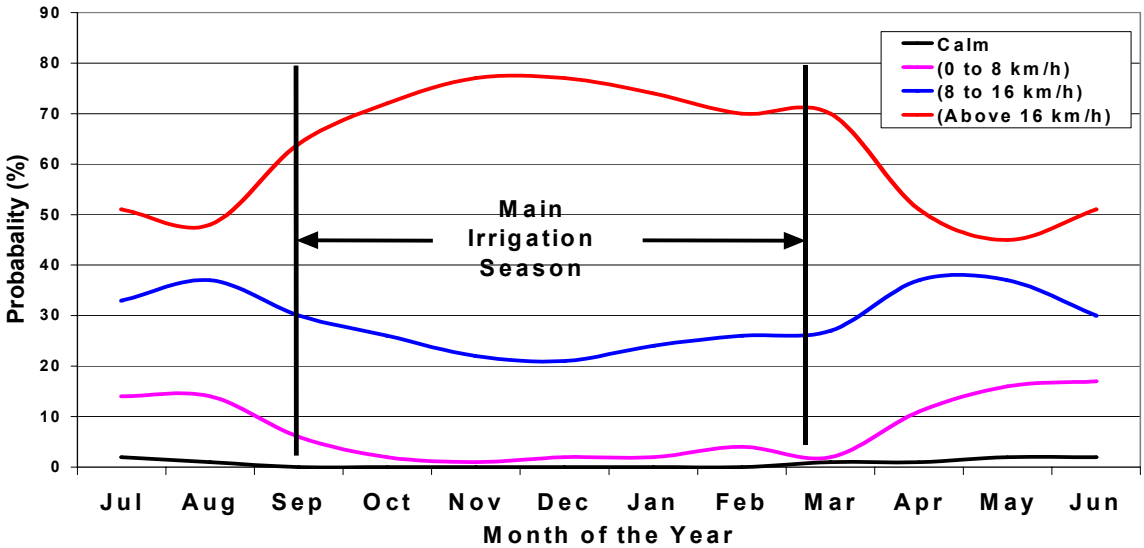


Figure 2.1 Probable wind speed expected at Perth during main irrigation season in the afternoon. (Data from Calder, 1992.)

The soils of the plain are medium to coarse sands and have a poor ability to hold both water and nitrogen fertiliser. The sandy soil and the poor uniformity of many irrigation systems result in growers applying large amounts of water and nitrogen fertiliser as compared to other vegetable growing areas in the world. On the Swan Coastal Plain vegetable crops are usually irrigated daily or twice daily by overhead sprinklers at about 150 per cent of pan evaporation. Leaching of fertiliser often results in high concentrations of nitrate in the ground water below horticultural properties (Lantzke, 1997). Monitoring studies have shown that with current industry practice around half of the irrigation and nitrogen that is applied is leached past the root zone (Sharma, 1991).

To address the lack of information on appropriate sprinkler irrigation design for windy conditions a comprehensive sprinkler testing program was conducted by the Western Australian Department of Agriculture. Twenty nine sprinkler/nozzle combinations from six sprinkler manufacturers were tested over a range of wind speeds. The data collected was analysed for its distribution uniformity and scheduling coefficient using SPACE Pro™ software.

The uniformity of any sprinkler system depends largely on the combination of sprinkler and nozzle selection, operating pressure and spacing (Christiansen, 1942). In addition to these factors, wind speed and direction are the primary factors causing distortion in the uniformity of irrigation. Any sprinkler system operating under outside conditions must be designed to take into consideration the effect of wind on its performance. Some of the indicators that help evaluate the performance of a sprinkler system are Distribution Uniformity (DU), Christiansen's Coefficient of Uniformity (CU) and Scheduling Coefficient (SC). These indicators and other technical terms that are used in this report are defined in the key definitions section.

Irrigation designers consider the trade off between the initial capital cost of an irrigation system and future operating expenses. The designer aims to optimise profit by the farmer over the life of the irrigation system. Where water is readily available and has a low cost the designer may install a system with a poorer uniformity and accept the higher operating costs associated with running the system longer to cover drier areas within the wetting pattern. This however may lead to offsite environmental costs such as salinity and ground water contamination due to leaching of nutrients. For a farmer in a situation where water is limiting or a penalty in yield occurs by over watering, maximum profit is obtained by installing a more costly but more uniform irrigation system.

Key definitions

Rotating sprinkler:	Device which by its rotating motion around its vertical axis distributes water over a circular area or part of a circular area.
Nozzle:	Aperture of the sprinkler through which the water is discharged. It may refer to either a single nozzle, or to a combination of nozzles in a multi-nozzled sprinkler.
Minimum effective pressure:	Lowest working pressure declared by the manufacturer, measured near the base of the sprinkler at a point situated about 0.2 m below the main nozzle of the sprinkler.

Key definitions (continued)

Maximum effective pressure: Highest working pressure declared by the manufacturer, measured near the base of the sprinkler at a point situated about 0.2 m below the main nozzle of the sprinkler.

Range of effective pressure: Pressure range between the minimum effective pressure and the maximum effective pressure declared by the manufacturer as the pressure range in which the sprinkler operates effectively.

Test pressure: Water pressure within the range of the effective pressure used for testing the sprinkler.

Nominal flow rate: Quantity of water per unit of time discharged by a sprinkler with a specific nozzle at the test pressure declared by the manufacturer in the manufacturer's data sheet.

Radius of throw: Farthest distance measured while the sprinkler is rotating normally, from the sprinkler centre-line to the point at which the sprinkler deposits water at the minimum rate of 0.25 mm/h for a sprinkler whose discharge exceeds 74 l/h, and 0.13 mm/h for a sprinkler whose discharge is equal to or less than 75 l/h.

Effective diameter of coverage: Twice the radius of throw

Trajectory angle: Angle of the water stream above a horizontal plane as discharged from the sprinkler nozzle operating at the test pressure.

Sprinkler spacing: Distance between sprinklers along the irrigation laterals.

Lateral spacing: Distance between adjacent laterals.

Wind speed: Average wind speed at the test site during the test of distribution uniformity of the sprinkler.

Water application rate: Mean depth of water applied to an area irrigated in a unit of time (for example, millimetre per hour).

Collector: Receptacle used for collecting the water discharged by the sprinkler during the est of distribution uniformity.

Co-efficient of Uniformity (CU): Christiansen developed the following formula for calculating the co-efficient of uniformity (CU):

$$CU = 100\left(1 - \frac{\sum \left| h_m - h_i \right|}{n \times h_m}\right)$$

where:

CU : co-efficient of uniformity
n : number of readings
h_m : arithmatic average of the reading
h_i : individual reading at each collector

$\sum \left| h_m - h_i \right|$: sum of the absolute values of the individual deviations from the average.

Key definitions (continued)

Co-efficient of Uniformity (CU) (continued):

The co-efficient of uniformity (CU) is an estimate of the uniformity of the sprinkler pattern based on an average of the entire area. The industry standard for agricultural applications requires the CU to be above 85 per cent. The draw back in using the CU to rate sprinkler system performance is that it treats over- and under-watered areas in the same way because of using the aboslute value of the deviation from the mean. Since it is an average, it gives no indication of how bad the coverage might be in localised areas. Therefore the DU and SC were used in this study to evaluate sprinkler uniformity.

Distribution of Uniformity (DU):

Distribution uniformity is defined as the percentage of the average of the lowest 25 per cent of the application rate to that of the mean application rate of the entire pattern. The internationally accepted standard for DU is a minimum of 75 per cent.

$$DU = \frac{d_{avg25}}{d} \times 100$$

where:

d_{avg25} = average of the lowest 25 per cent of the application rates in the sprinkler pattern

d = mean application rate of entire pattern.

Scheduling Co-efficient (SC):

The scheduling co-efficient is a fraction used to determine the length of time that a sprinkler system should be run to account for sprinkler uniformity at the driest area. For example, a system operating at 100 per cent uniformity has a scheduling co-efficient of 1.0. A system with a SC of 1.5 means that we have to run the system for an extra 50 per cent to achieve the same precipitation (as in the above case 100 per cent uniformity) to bring the driest area up to the average. There is no critical limit defined for SC in the irrigation industry however, a SC of 1.4 has been used in this study as maximum acceptable limit.

$$SC = \frac{d}{d_{lowest}}$$

where:

d = mean application rate of entire area.

d_{lowest} = average lowest application rate in the 5 per cent window size of the entire area OR a minimum of four catch cans.

2.2 Materials and methods

2.2.1 Set up of test site for sprinkler testing

A sprinkler-testing site was selected adjacent to the grounds of Water and Rivers Commission in South Perth (lat. 31 56 S and long. 115 50 E) as per the International Standards ISO 7749 - 1 and 2 (1995) test guidelines. The site selected was a park evenly leveled with a maximum slope of one percent and free from trees and buildings to avoid any restriction to the prevailing wind speed from any direction. A grid of 50 m x 50 m was marked at 2 m x 2 m spacing on the park (Figure 2.2). Figure 2.3 is a photograph of the site showing the catch-cans and sprinkler head.

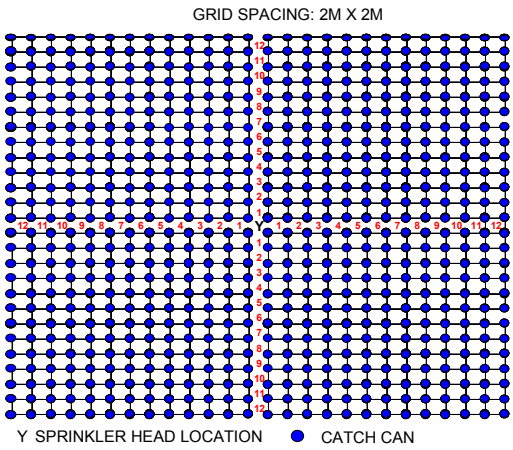


Figure 2.2. Catch-can layout for sprinkler uniformity test.

Figure 2.3 Photograph showing layout for sprinkler uniformity test.

A single sprinkler mounted on a riser of height 1.2 metres was installed in the centre of the square grid. A water tank and a pump were installed with a control mechanism to maintain the desired test pressure recommended for different sprinklers. Pressure gauges installed at the pump and 350 mm below the sprinkler head (Figure 2.4) were used in conjunction with a back-flow control valve to regulate the operating pressure to that recommended by the manufacturer. Uniform catch-cans of opening diameter 135 mm and height of 125 mm (Figure 2.5) were placed in a 2 m x 2 m grid. To monitor wind speed and its direction at a height of 2 metres during the test period an anemometer (UNIDATA® Model 6504 - FS) was installed within 50 m of the test site (Figure 2.6). The operating pressure at the riser gauge was adjusted to the prescribed pressure by starting the pump while the sprinkler head was covered. This was done with a bucket so as not to allow the water particles to fall in the catch-cans. Each test was run for one hour, the minimum recommended duration in the test code. Figure 2.7 shows a test in progress.

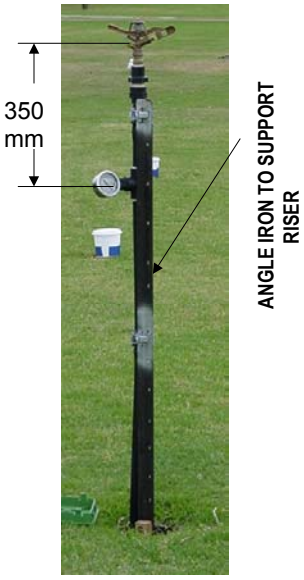


Figure 2.4. Riser assembly.

Figure 2.5 Catch-can used to collect precipitation.

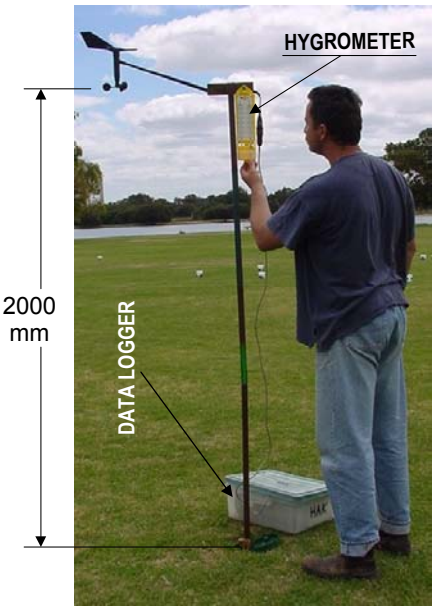


Figure 2.6. Wind anemometer assembly uniformity test.

Figure 2.7 Sprinkler uniformity test in progress.

Local sprinkler suppliers were asked to supply impact sprinklers that would be suitable for lateral spacings of 12 metres or greater. Six different brands of sprinkler heads comprising 29 different nozzle sizes/combinations were tested under low to high wind conditions. To eliminate the effect of wind direction on rectangular spacings a program in GENSTAT was developed to align the wind direction perpendicular to the laterals and compute precipitation as if it occurred under that wind direction. SPACE PRO™ was used to compute the distribution uniformity and scheduling coefficient. A list of the sprinklers and nozzles tested is given below in Table 2.1.

Table 2.1 List of sprinklers tested

Manufacturer	Model	Jet size
HR Products	Senninger	3.2 mm
	HR46C	4.76 mm
		4.76 x 3.2 mm
Martin	Cropwell	4.0 mm
		4.0 x 2.5 mm
Nelson windfighter	R2000WF	Gold WF#18
		Red WF#16
		Green WF#14
NAAN	5024	3.2 mm
	322	3.5 mm
		3.5 x 2.5 mm
	5035	5.0 mm
		5.0 x 2.5 mm
Toro	Pope premier	10#
		10 x 6
		12
		12 x 6
	Rainspray Model 2	12
		12 x 8
		14
		14 x 8
	TR2	11#
		11 x 6
		14
		14 x 8
		12 x 8
		14
		14 x 8
Rainbird	20J	3.97 mm
	30BH	3.97 x 2.38 mm
		4.76 x 3.17 mm
	48H	5.2 mm

#: 10 represents 10/64 of an inch.

2.2.2 Data recording

The data was recorded for each of the sprinkler tests using Sheet 1 and Sheet 2 (specimens on the following pages). The preliminary information on the test number, date and time of test (start/finish) and the team members were recorded. Information on the sprinkler

manufacturer and model, single/double nozzle, the size of the nozzle, operating pressure (at pump and at riser) and discharge were recorded before each test.

Wind speed and direction data were recorded every 30 seconds using Unidata Starlog® 6003B data logger for the one-hour duration of the test. The precipitation collected in catch-cans was measured using 100 ml measuring cylinder (Figure 2.8). Two people were employed to measure while the third person quickly recorded in the format shown in Sheet 2 so as to minimise evaporation losses while recording. The entire grid was divided in to four quadrants and the first measurement was taken from the catch-can located at point 1 in first quadrant and then taken in the direction of the arrow marked. The process was repeated likewise for all other quadrants. It took between 15-25 minutes to measure precipitation in all the catch-cans.

Figure 2.8. Measuring precipitation in catch-cans.

SHEET 1

EFFECT OF WIND SPEED ON SPRINKLER UNIFORMITY

TEST NO: .....

DATE: ..... /...../ .....

TIME OF TEST: **START:** ..... **FINISH:** .....

TEAM MEMBERS: .....

SPRINKLER INFORMATION

SPRINKLER MAKE & ..... **NOZZLE SIZE:** ..... mm

TYPE: ..... **SINGLE/DOUBLE** .....

SPRINKLER DISCHARGE: ..... litres/min

PRESSURE **AT PUMP** ..... kPa

AT RISER ..... kPa

RELATIVE HUMIDITY ..... **%**

DRY BULB AIR TEMP: ..... Degree Celsius

WET BULB AIR TEMP: ..... Degree Celsius

WIND SPEED INFORMATION

MAXIMUM SPEED: ..... metres/sec

MINIMUM SPEED: ..... metres/sec

AVERAGE SPEED ..... metres/sec

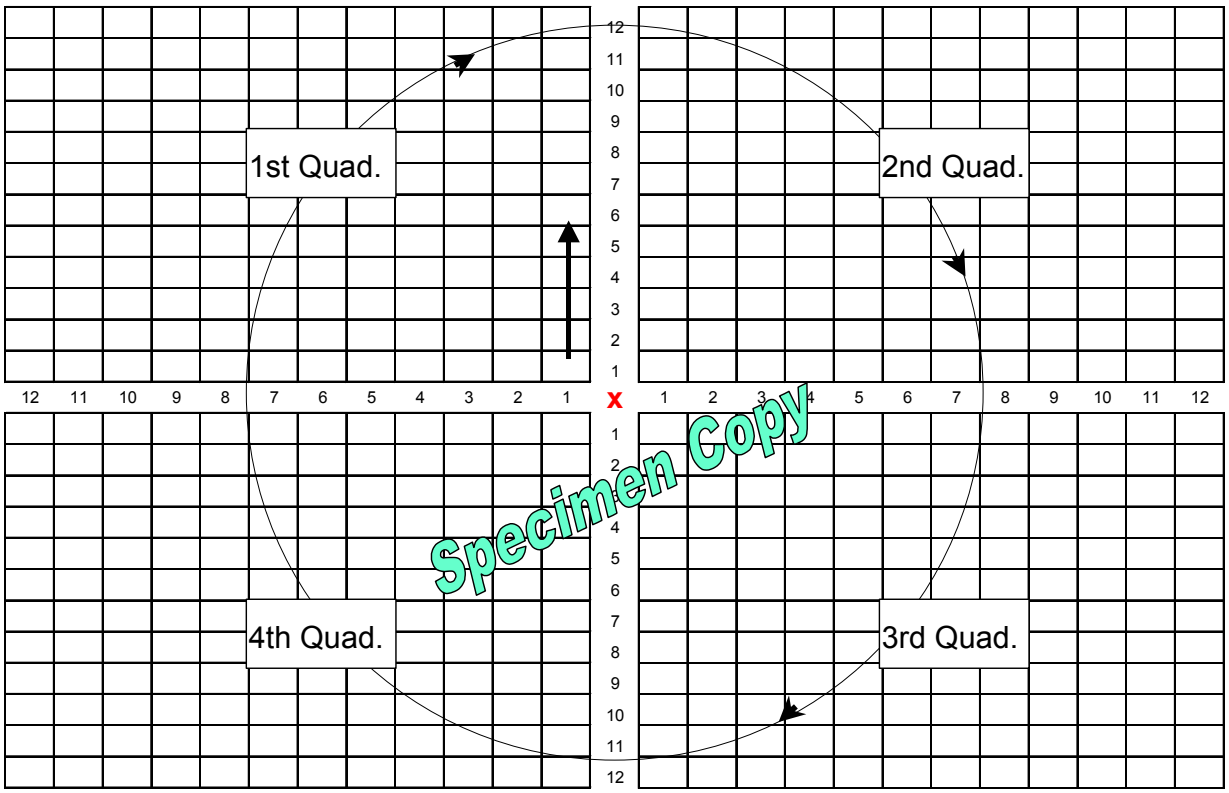
STANDARD DEVIATION (SPEED) .....

AVERAGE WIND DIRECTION: .....

STANDARD DEVIATION (DIRECTION): .....

SHEET 2

TEST NO:_____



X Sprinklerhead location.

2.2.3 Data retrieval and analysis

Wind speed and wind direction data from the Unidata Starlog® 6003B data logger was downloaded to a PC. The raw data (Figure 2.9) was transferred to an Excel Worksheet for determining the maximum, minimum, and average wind speed. Calculations for average wind direction during the one-hour run were also made in addition to the standard deviation for the wind speed and the direction. When the wind direction or speed changed significantly during the test the data was discarded. In some cases data did not fit the trend of the other tests and this data was also discarded. Uniformity results which did not fit the trend of the other data were probably due to variations in wind speed and direction during the test - that were not severe enough to be discarded because of their high standard of deviation of either wind speed or direction. The precipitation data collected in Sheet 2 was entered in to an Excel Worksheet so it could be analysed by the **S**prinkler **P**rofile **A**nd **C**overage **E**valuation program (SPACE Pro™).

Time when the data logger was connected to the Anemometer

```
Date       Time     W/Sp W/Dir.
09/03/2000 9:44:00, 0.0, 00
09/03/2000 9:44:30, 0.0, 00
09/03/2000 9:45:00, 0.0, 00
09/03/2000 9:45:30, 0.0, 00
09/03/2000 9:46:00, 1.1, 41
09/03/2000 9:46:30, 2.2, 39
09/03/2000 9:47:00, 1.3, 42
09/03/2000 9:47:30, 2.5, 34
09/03/2000 9:48:00, 2.5, 48
09/03/2000 9:48:30, 2.5, 41
09/03/2000 9:49:00, 2.5, 29
09/03/2000 9:49:30, 1.3, 29
09/03/2000 9:50:00, 2.2, 53
09/03/2000 9:50:30, 2.8, 47
09/03/2000 9:51:00, 1.0, 36
09/03/2000 9:51:30, 1.4, 41
09/03/2000 9:52:00, 1.0, 75
.. .. .. .. .. .. .. .. ..
.. .. .. .. .. .. .. .. ..
.. .. .. .. .. .. .. .. ..
```

Figure 2.9. Wind speed and wind direction data.

SPACE PRO™ for square configuration

SPACE Pro™ is a powerful analytical tool giving irrigation designers the ability to evaluate and compare sprinkler designs. SPACE Pro™ allows designers to place sprinkler heads in almost any configuration, calculate the uniformity and then graphically display the coverage using the actual sprinkler test data. Designers can compare the uniformity of different sprinkler layouts to assess the feasibility of upgrading an existing system or choosing a new system. SPACE Pro™ allows the user to overlap precipitation from a single sprinkler test in either square, triangular or rectangular configuration and at different sprinkler spacings. SPACE Pro™ can then determine the coefficient of uniformity, distribution uniformity and scheduling co-efficient for that configuration.

How SPACE Pro™ is used

An example of the use of SPACE Pro™ in square configuration is given below.

Step 1:

The sprinklers specifications, test number, time and date of testing, number of columns and rows in which precipitation falls and the catchment spacing are entered in new grid screen as shown in Figure 2.10. After clicking ***Continue*** in the same screen, the precipitation data is imported from the Excel workbook and pasted as shown in Figure 2.11. The ***Assign Head Position Button*** as shown Figure 2.11 is clicked to enter location of first point on the first quadrant (please refer to **Sheet 2**). The red dot marked in Figure 2.12 indicates the position of the sprinkler head.

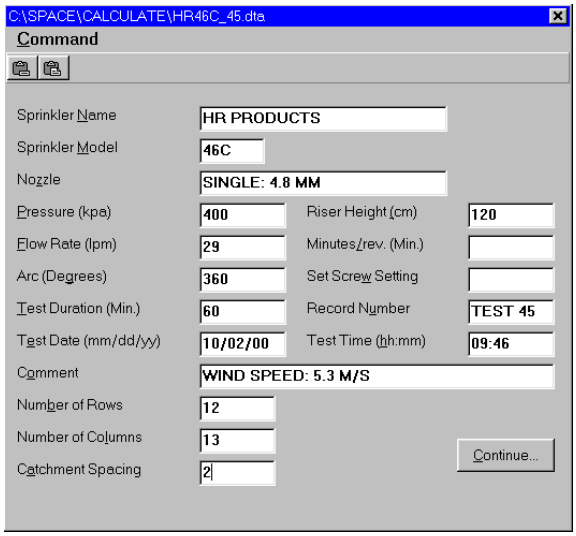


Figure 2.10. Screen showing basic sprinkler information.

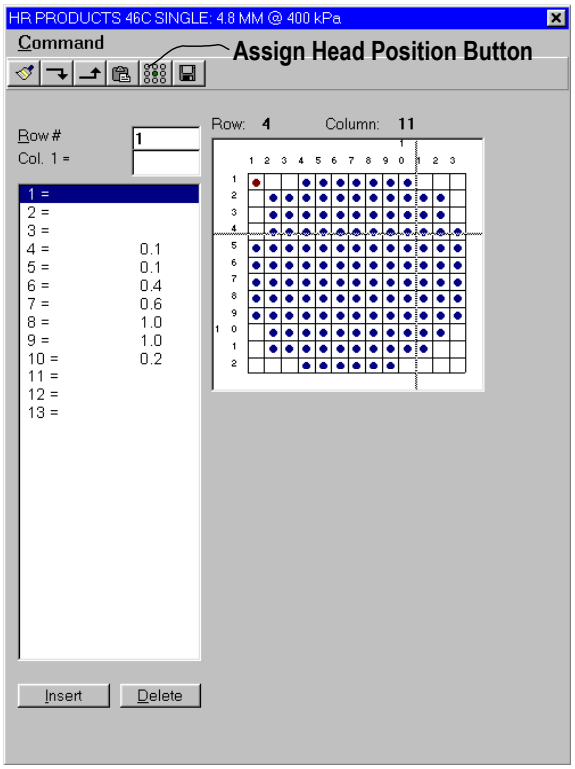


Figure 2.11 Importing sprinkler precipitation data.

Step 2:

By clicking the ***Overlap*** button in Figure 2.13, a window as shown in Figure 2.14 appears which allows the configuration and sprinkler spacing to be entered.

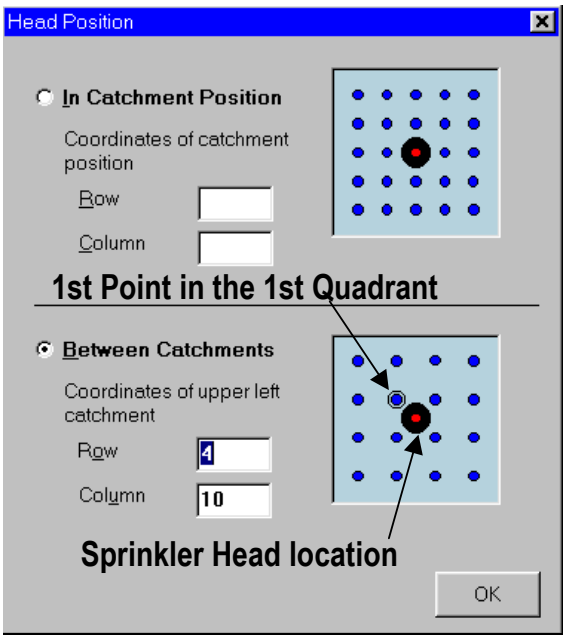


Figure 2.12. Marking location of first point in the first quadrant.

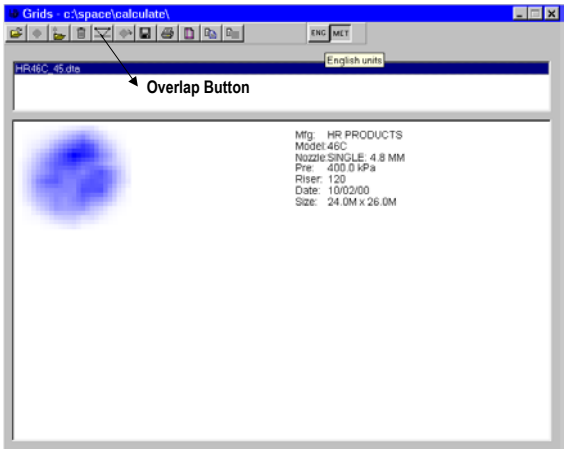


Figure 2.13 Sprinkler pattern as seen after entering percipitation data.

By clicking the ***Densogram*** button shown in Figure 2.14, the screen as shown in Figure 2.15 will appear. It gives the value of CU, DU, and SC while indicating the driest and the wettest spots created within the four sprinklers.

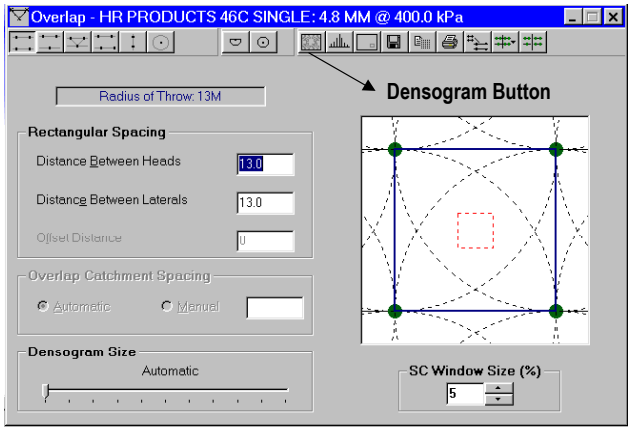


Figure 2.14. Determining CU, DU and SC in square or any other configuration.

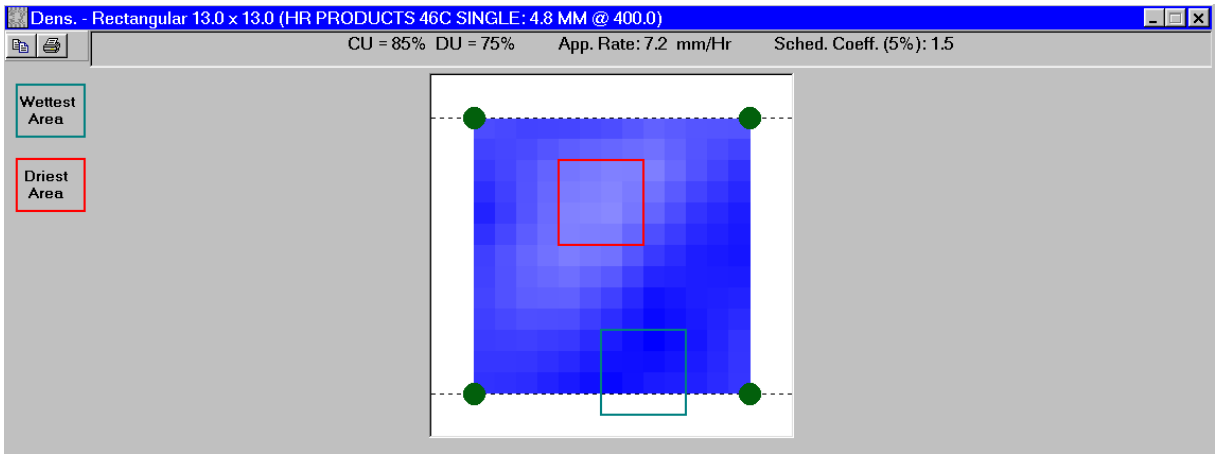


Figure 2.15. Uniformity statistics and densogram.

Genstat for rotating and aligning catch can data for rectangular spacings

The direction of wind relative to the sprinklers will affect the uniformity of sprinkler systems. To eliminate the effect of wind direction on uniformity a program was developed in GENSTAT to rotate and align the grid from the same wind direction before importing the precipitation values into SPACE Pro.

Irrigation systems are usually designed with a lateral spacing which is greater than the sprinkler spacing. This decreases the number of lateral pipes required and reduces the installation cost. To increase uniformity the laterals are normally aligned at right angles to the dominant wind direction. If the wind direction is parallel to the laterals then a lower uniformity will result because the wetting pattern is 'tunnelled' down the laterals as the sprinklers do not throw to the other lateral. For the same speed wind the uniformity will be better for rectangular configurations when the wind direction is at right angles to the laterals. In this study the catch can data was rotated to align the wind direction at right angles to the laterals.

2.3 Results and recommendations

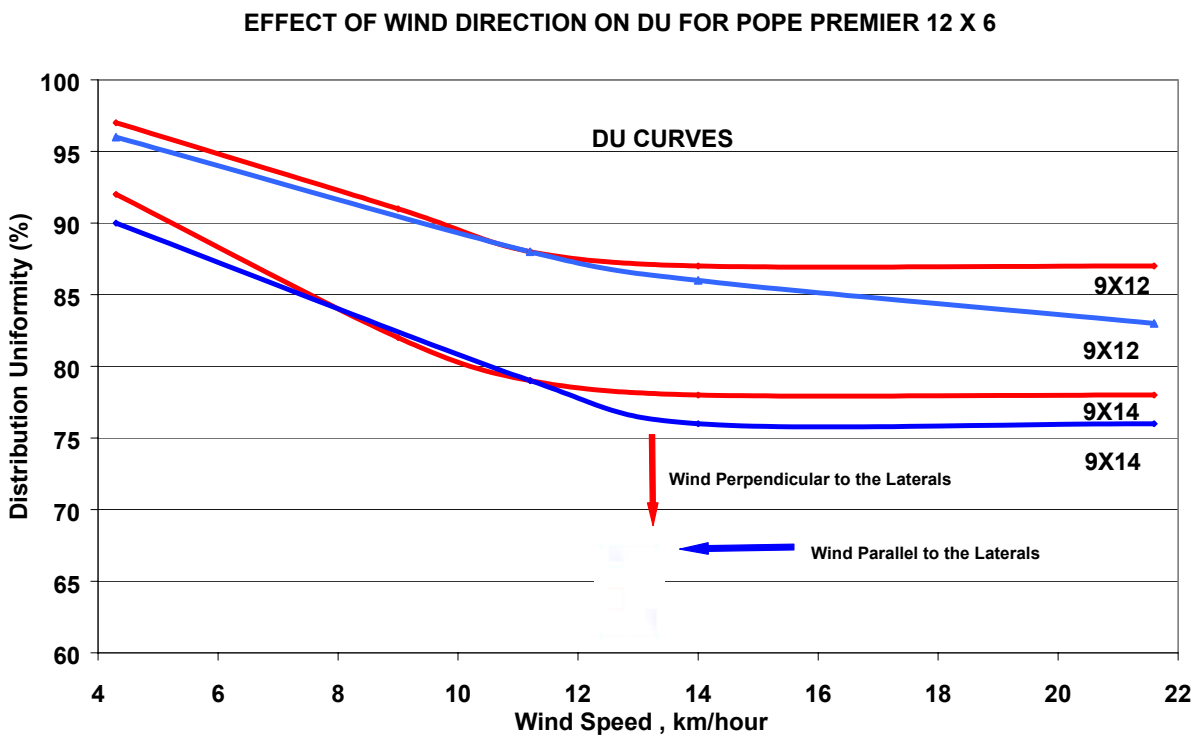
Each sprinkler was tested over a range of low to high wind speeds. The distribution uniformity (DU) and scheduling coefficient (SC) of each test was plotted against the wind speed to show the effect of wind speed on sprinkler uniformity. The DUs and the SCs at different lateral and sprinkler spacings are graphed. This allows the designer to choose the appropriate sprinkler spacing for the wind speed on the property. The commonly accepted standard is that DU should be a minimum of 75 per cent. There is no critical limit defined for SC in the irrigation industry however in the study SC below 1.4 is used as an acceptable maximum limit.

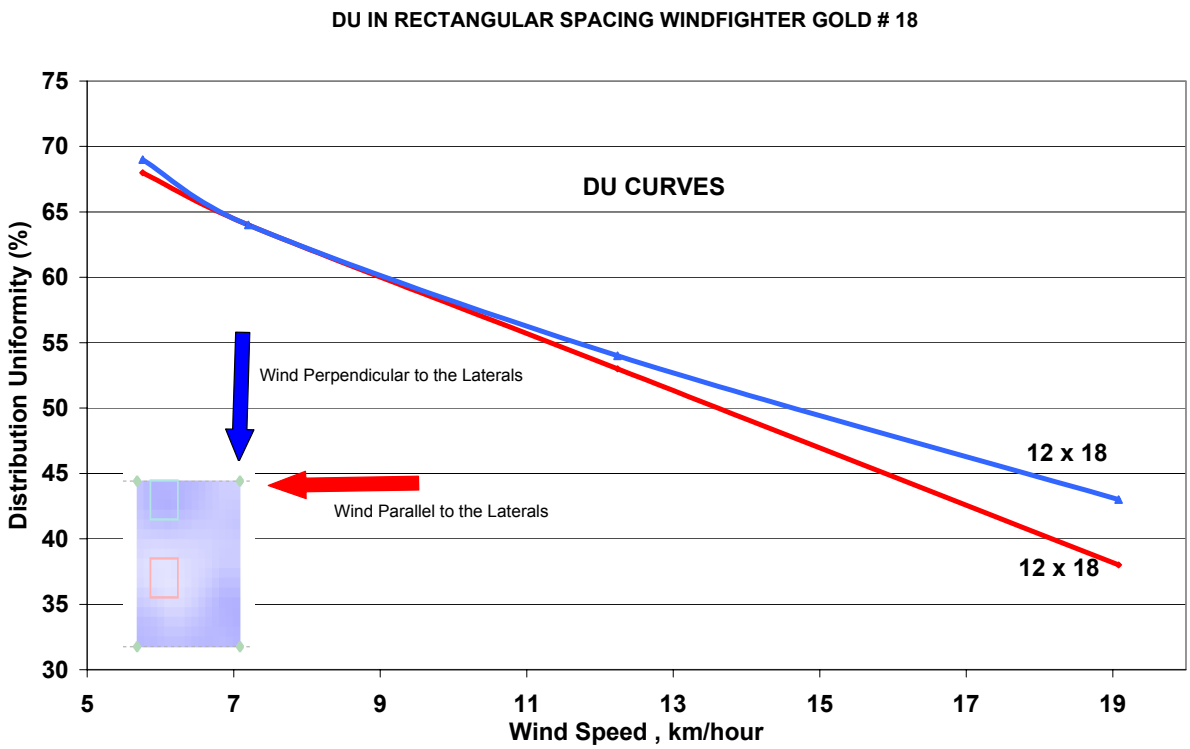
Uniformity data is presented first for sprinklers in a square configuration. Both the DU and SC data are presented in the same graph with DU scale on the left axis and SC scale on the right axis.

Uniformity data is then presented for the sprinkler in a range of rectangular configurations. The performance of sprinklers in rectangular spacing was evaluated by aligning the wind direction perpendicular to the lateral. The GENSTAT program was used as described in Data Retrieval and Analysis section to align the wind directions for the tests carried out. This was necessary to study the effect of wind speed only on the DU and SC. The wind direction effect on the DU and SC has thus been eliminated under rectangular spacing configuration.

Aligning wind direction perpendicular to the laterals results in the best uniformity for that sprinkler. To reduce installation costs the distance between the laterals is usually greater than the distance between sprinklers as this allows fewer laterals to be used. If the wind was aligned parallel to the laterals the sprinkler wetting pattern is ‘tunnelled’ down the laterals and a dry area occurs in the centre of the laterals. Figures 2.16 and 2.17 show the effect of wind direction relative to the lateral for two sprinklers. It can be seen that when the wind direction is perpendicular to the laterals the uniformity is greater than when the wind direction is parallel to the laterals. This is particularly true at higher wind speeds. Consequently the uniformity data presented in this report for rectangular spacings (where wind direction has been rotated to that perpendicular to the laterals) may be better then that experienced under field conditions for locations where the wind comes from varying directions.

For each sprinkler recommendations on appropriate spacings for windy conditions are given.





Figures 2.16 and 2.17. Effect of wind direction on uniformity at a rectangular spacing for two sprinklers.

2.3.1 HR PRODUCTS™

Model: **HR 46C single nozzle**
Jet size(s): 4.76 mm
Test pressure: 400 kPa
Flow rate: 29.0 litres/minute
Diameter of throw: 31.5 metres

Results

Six tests were conducted on the HR46C single nozzle (4.76 mm) at an operating pressure of 400 kPa for average wind speeds between 5.4 and 19.1 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.2.

Table 2.2 Prevailing wind speed and wind direction during testing of HR46C single nozzle: 4.76 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
44	9.0	22.3	0.0	1.3	106	36
45	19.1	31.3	7.2	1.4	117	16
46	13.0	22.7	2.9	1.3	137	21
114	5.4	14.8	0.0	0.9	105	108
193	6.5	13.7	0.0	0.8	18	40
195	8.3	16.6	2.9	0.8	247	25

* Test 114 had a high SD of wind direction. This data was not discarded as the wind speed was very low.

Square configuration

The DU at a 12 m x 12 m spacing decreases as the wind speed but remains above the international acceptable minimum level of 75 per cent (Figure 2.18). The SC for this spacing is below the maximum acceptable limit of 1.4. At a spacing of 13 m x 13 m the DU and SC were acceptable at low wind speeds only. For all other square spacings tested the DU was below the acceptable minimum limit of 75 per cent at all wind speeds.

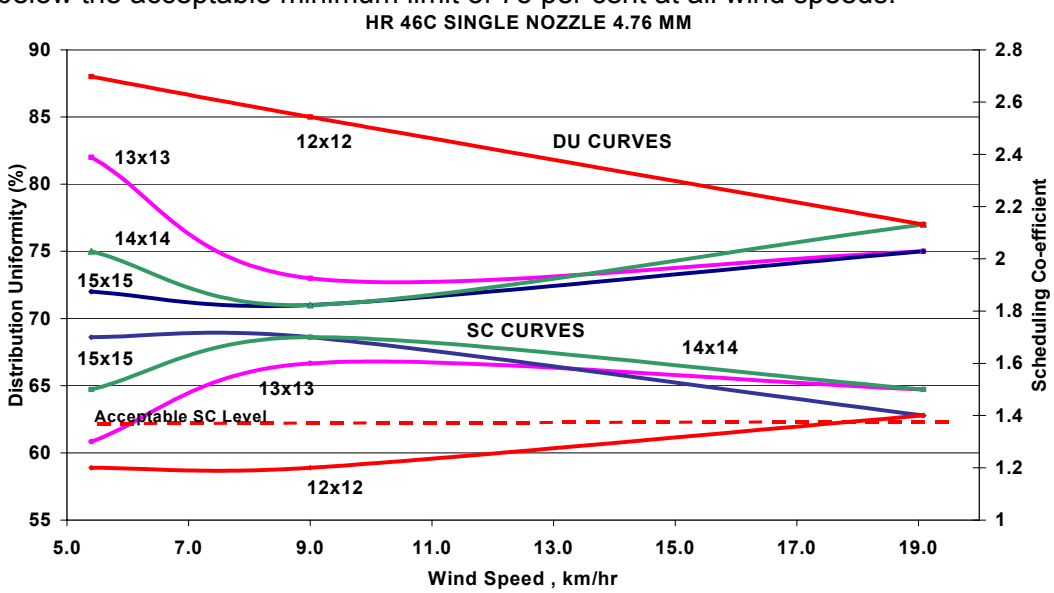


Figure 2.18. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The sprinkler performed well at spacings of 9 m x 12 m, 9 m x 14 m and 9 m x 15 m. The sprinkler had a DU above 75 per cent at spacings of 12 m x 14 m, 12 m x 15 m and 12 m x 16 m for all wind speeds tested, though uniformity did decrease as wind speed increased (Figure 2.19). This sprinkler did not meet the acceptable DU and SC criteria when spaced at 14 m x16 m.

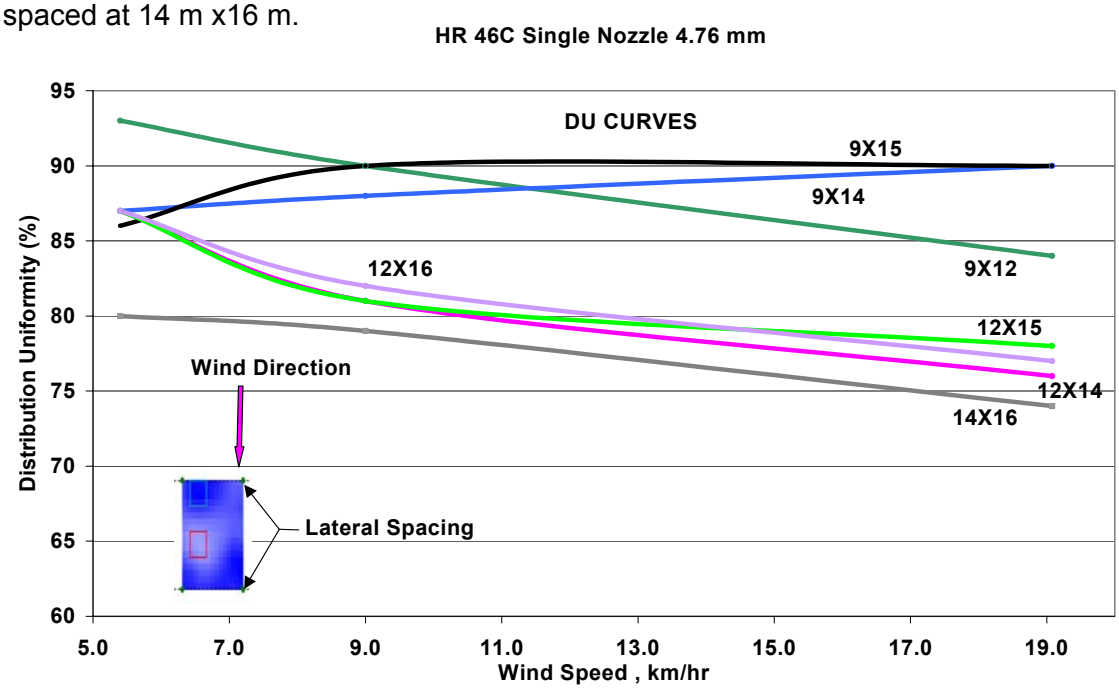


Figure 2.19. Effect of wind speed on distribution uniformity.

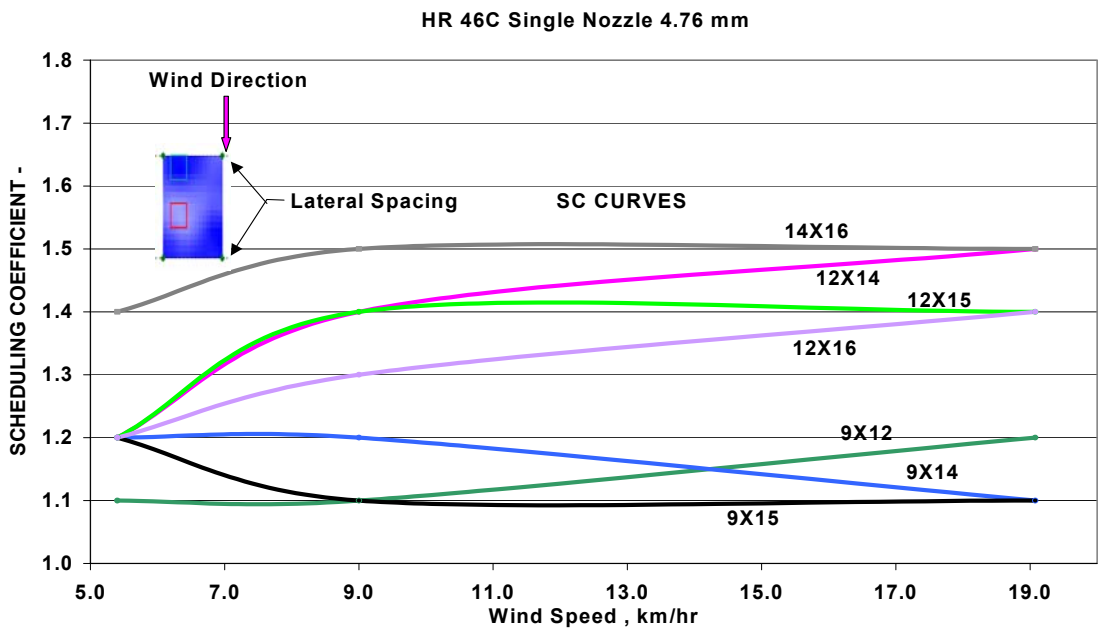


Figure 2.20. Effect of wind speed on scheduling coefficient.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m.
Rectangular configuration: 9 m x 12 m, 9 m x 14 m and 9 m x 15 m.

Model: **HR 46C double nozzle**
Jet size(s): 4.76 mm x 3.2 mm
Test pressure: 400 kPa
Flow rate: 42.9 litres/minute
Diameter of throw: 31.5 metres

Results

Seven tests were conducted on the HR46C double nozzle (4.76 mm x 3.2 mm) at an operating pressure of 400 kPa for average wind speeds between 4.0 and 15.1 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.3.

Table 2.3 Prevailing wind speed and wind direction during testing of HR46C double nozzle: 4.76 mm x 3.2 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
1	7.9	19.4	0.0	1.3	92	51
2	5.8	16.2	0.0	1.3	116	96
3	4.0	16.2	0.0	1.2	76	48
4	9.7	25.2	2.5	1.1	251	26
131	15.1	28.1	6.5	1.3	216	15
157	15.1	28.8	4.7	1.2	196	10
196	10.8	24.1	1.1	3.0	128	34

Square configuration

The DU at 12 m x 12 m and 14 m x 14 m spacing decreases but remains above the acceptable level of 75 per cent as the wind speed increases from an average of 4 km/hr to 15 km/hr (Figure 2.21). The SC for these spacings is generally below the acceptable maximum limit of 1.4. The DU at spacings of 15 m x 15 m and 16 m x 16 m fell below the acceptable minimum limit as wind speed increases.

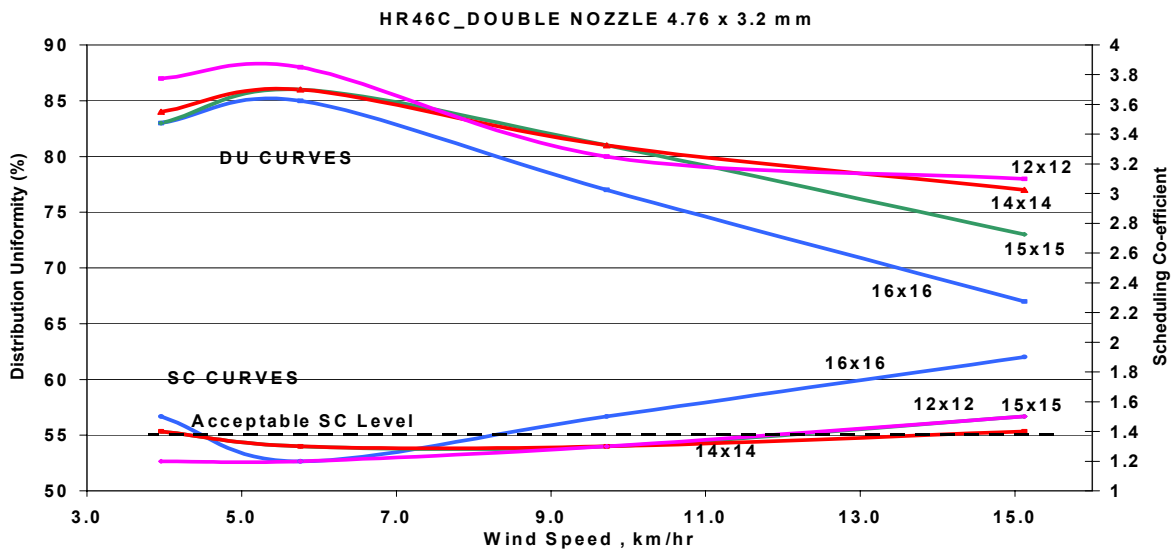


Figure 2.21. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The sprinkler had a DU above 75 per cent (minimum acceptable limit) across the range of wind speeds tested when spaced at 9 m x 12 m, 9 m x 14 m, 12 m x 14 m, 9 m x 15 m and 12 m x 15 m (Figure 2.22). At spacings of 12 m x 16 m and 14 m x 16 m the DU fell below 75 per cent and the SC increased above 1.4 as the wind speed increased (Figure 2.23).

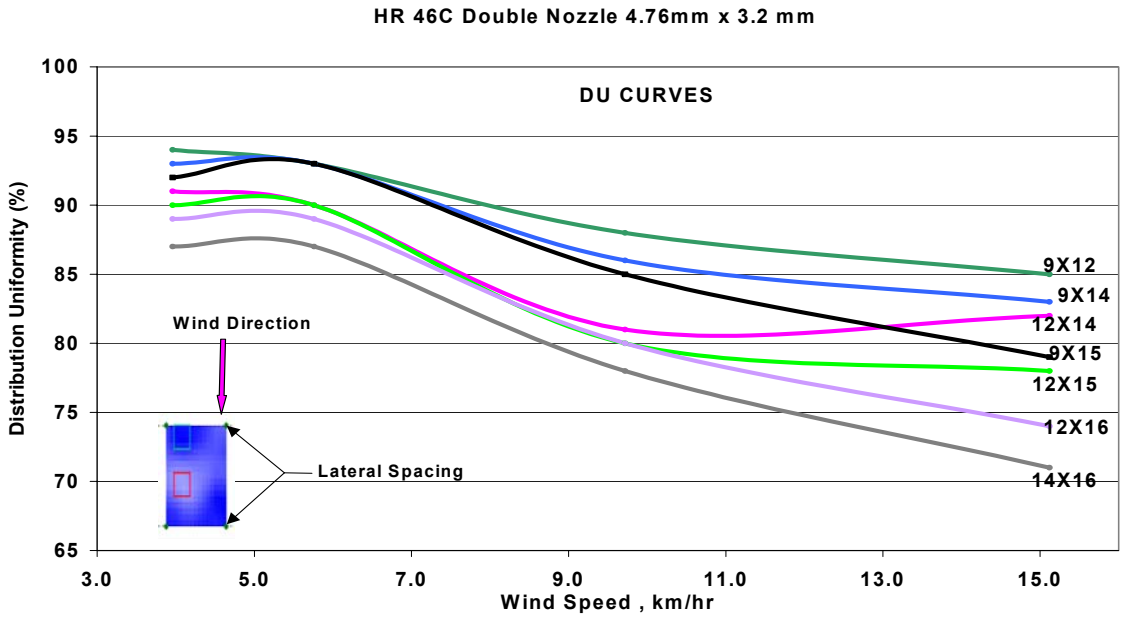


Figure 2.22. Effect of wind speed on distribution uniformity and scheduling coefficient.

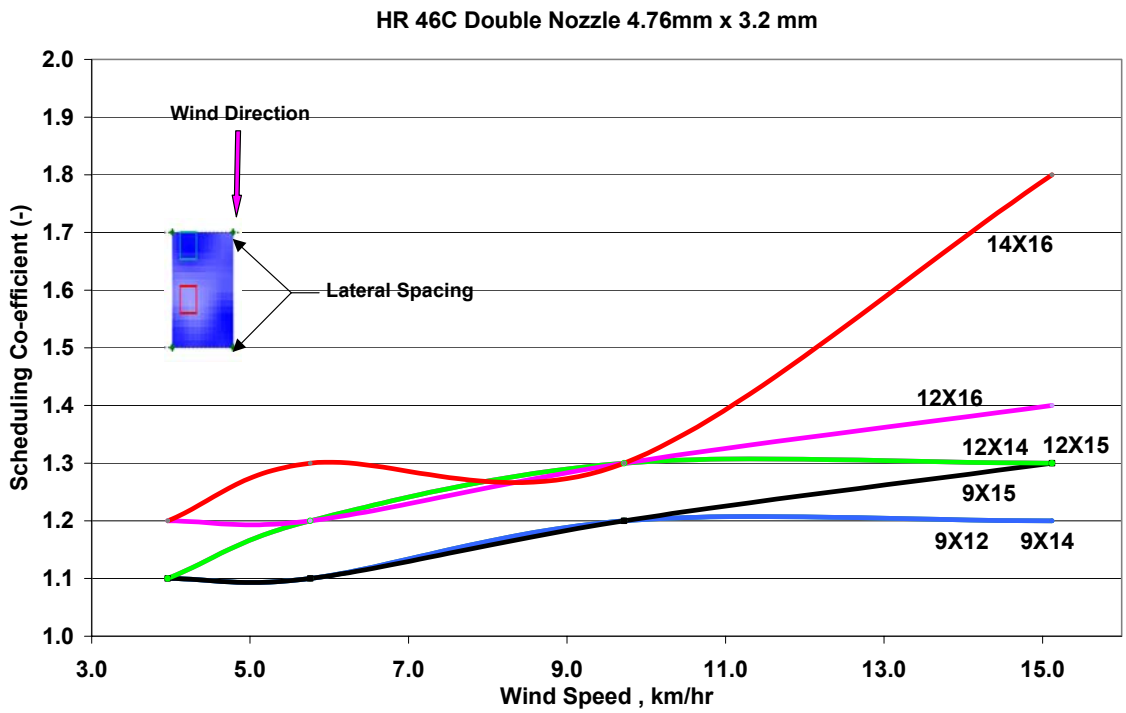


Figure 2.23. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m and 14 m x 14 m.
Rectangular configuration: 9 m x 12 m, 9 m x 14, 12 m x 14 m, 9 m x 15 m and 12 m x 15 m.

Model: **Senninger 3023**
Jet size(s): 3.2 mm
Test pressure: 385 kPa
Flow rate: 12.2 litres/minute
Diameter of throw: 29.0 metres

Results

Six tests were conducted on the Senninger 3023 single nozzle (3.2 mm) at an operating pressure of 385 kPa for average wind speeds between 4.0 and 17.3 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.4.

Table 2.4 Prevailing wind speed and wind direction during testing of Senninger 3023 single nozzle: 3.2 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
10	4.0	9.7	0.0	0.6	143	48
11	4.0	7.9	0.0	0.5	312	48
104	8.6	19.8	2.5	0.7	291	45
108	10.8	18.7	5.0	0.8	241	25
147	17.3	32.8	5.0	1.4	206	17
156	12.6	20.5	4.0	1.0	27	9

Square configuration

The Senninger 3023 single nozzle 3.2 mm sprinkler did not meet the acceptable DU (> 75 per cent) nor the scheduling coefficient (< 1.4) criterion at any of the spacings tested (Figure 2.24).

Rectangular configuration

This sprinkler was not tested at rectangular spacings because of its poor performance at the square spacing 11 m x 11 m.

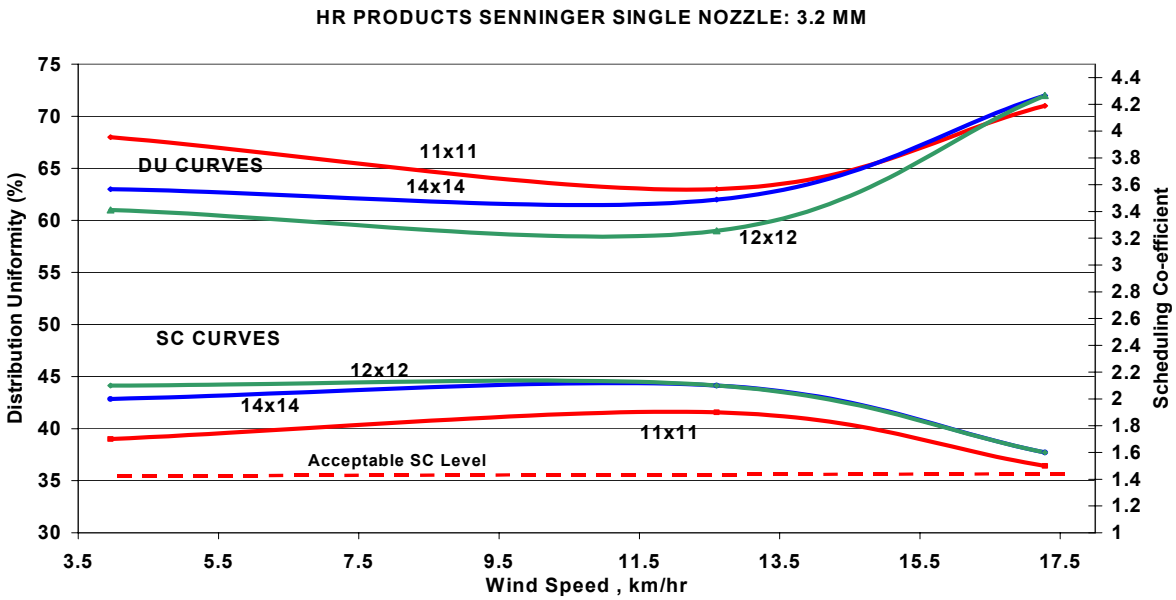


Figure 2.24. Effect of wind speed on distribution uniformity and scheduling coefficient.

Recommended spacing for windy conditions

Square configuration: Not recommended at spacings tested.
Rectangular configuration: Not recommended at spacings tested.

2.3.2 MARTIN CROPWELL™

Model: **Cropwell™ AG15**
Jet size(s): 4.0 mm
Test pressure: 350 kPa
Flow rate: 19.7 litres/minute
Diameter of throw: 24.8 metres

Results

Six tests were conducted on the Cropwell™ AG15 single nozzle (4.0 mm) at an operating pressure of 350 kPa for average wind speeds between 5.0 and 15.1 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.5.

Table 2.5 Prevailing wind speed and wind direction during testing of Martin Cropwell single nozzle: 4.0 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
47	15.1	29.9	3.6	1.5	140	19
48	5.0	11.5	0.0	0.6	132	49
71	9.4	25.2	0.0	1.1	160	26
123	13.7	24.1	2.9	1.2	207	19
163	10.8	22.3	1.1	1.4	148	13
165	10.8	21.6	1.4	1.2	154	28

Square configuration

The DU remained above the acceptable level (75 per cent) at all spacings except 14 m x 14 m at the wind speeds tested (Figure 2.25). The scheduling coefficient at 10 m x 10 m, 11 m x 11 m, 12 m x 12 m and 13 m x 13 m spacing is either below or just equal to 1.4, the maximum allowable.

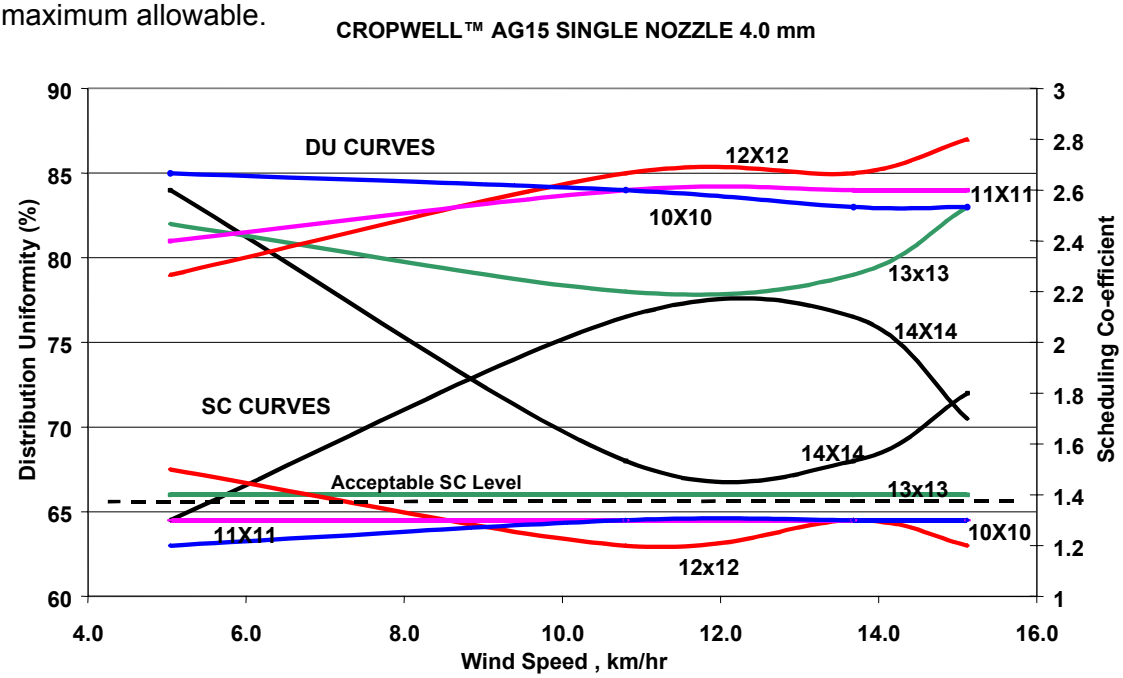


Figure 2.25. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

Cropwell™ AG15 single nozzle (4.0 mm) sprinkler had a DU above 75 per cent at the 9 m x 12 m, 9 m x 14 m and 12 m x 14 m spacings over the range of wind speeds tested (Figure 2.26). However the SC at 12 m x 14 m spacing rises above 1.4 when the wind speed increases beyond 6 km/hr. When spaced at 9 m x 15 m and 12 m x 15 m the DU for this sprinkler fell below 75 per cent when the wind speed increased.

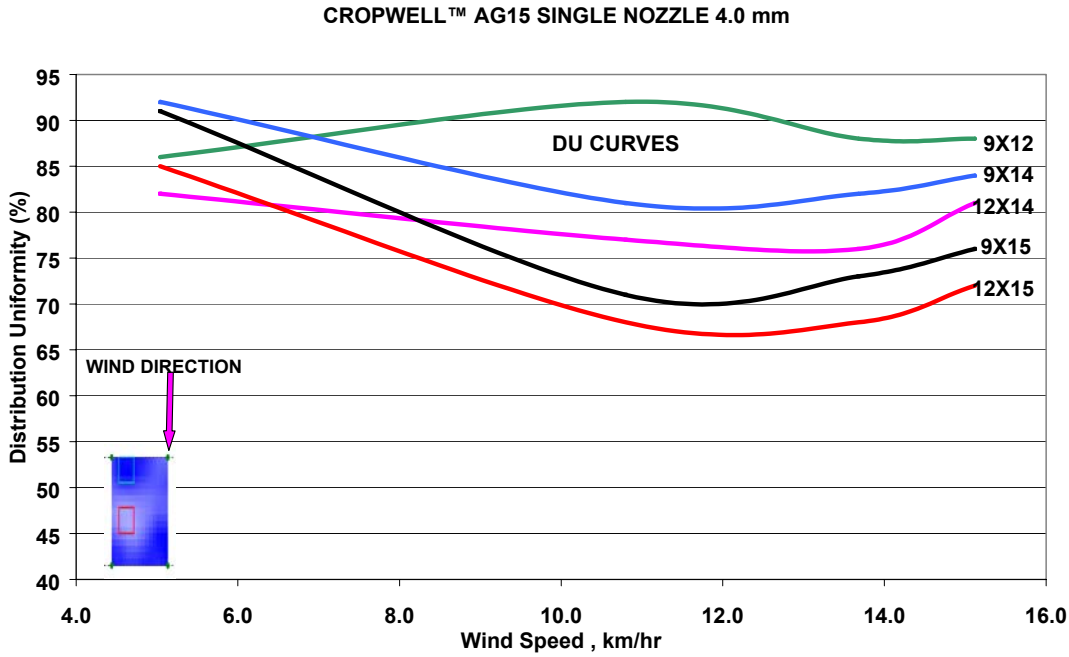


Figure 2.26. Effect of wind speed on distribution uniformity in rectangular configuration.

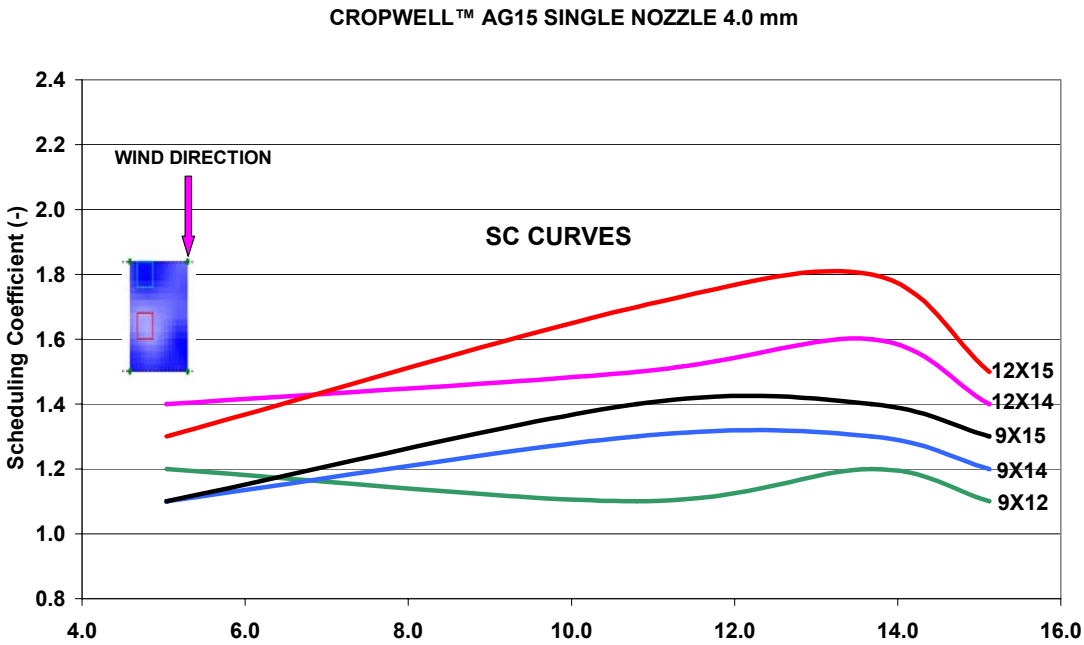


Figure 2.27. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 10 m x 10 m, 11 m x 11 m and 12 m x 12m.
Rectangular configuration: 9 m x 12 m and 9 m x 14 m.

Model: **Cropwell™ AG15**
Jet size(s): 4.0 mm x 2.5 mm
Test pressure: 350 kPa
Flow rate: 25.2 litres/minute
Diameter of throw: 24.8 metres

Results

Nine tests were conducted to evaluate the performance of the Cropwell™ AG15 double nozzle (4.0 mm x 2.5 mm) at an operating pressure of 350 kPa. The wind speed data measured during each test on this sprinkler is shown in Table 2.6. Six tests were conducted at a pressure of 350 kPa within the operating pressure range as prescribed by the manufacturer and three tests at varying pressures from 250 kPa to 400 kPa to study the effect of pressure on distribution uniformity.

Table 2.6 Prevailing wind speed and wind direction during testing of Martin Cropwell double nozzle: 4.0 mm x 2.5 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
5	4.3	10.4	0.0	0.5	259	41
50	12.2	21.6	5.0	1.1	248	16
51	10.4	22.7	0.0	1.1	88	24
62	15.5	25.6	5.4	1.2	226	19
137	8.3	19.8	0.4	1.0	87	34
145	19.8	33.1	7.6	1.6	212	12
159*	10.8	21.2	2.9	1.2	113	41
160*	12.2	22.3	4.0	1.1	112	22
161*	11.9	22.7	4.0	1.1	89	27

Square configuration

The DU values at spacings of 10 m x 10 m, 11 m x 11 m and 12 m x 12 m are well above 75 per cent (minimum acceptable level) and corresponding scheduling coefficient is below 1.4 (maximum acceptable limit) over the range of wind speeds tested. The DU at 13 m x 13 m spacing drops below 75 per cent as the wind speed rises to 14 km/hr and the SC increases above 1.4. At a 14 m x 14 m spacing the DU is below 75 per cent and the SC is above 1.4 for all wind speeds tested (Figure 2.28).

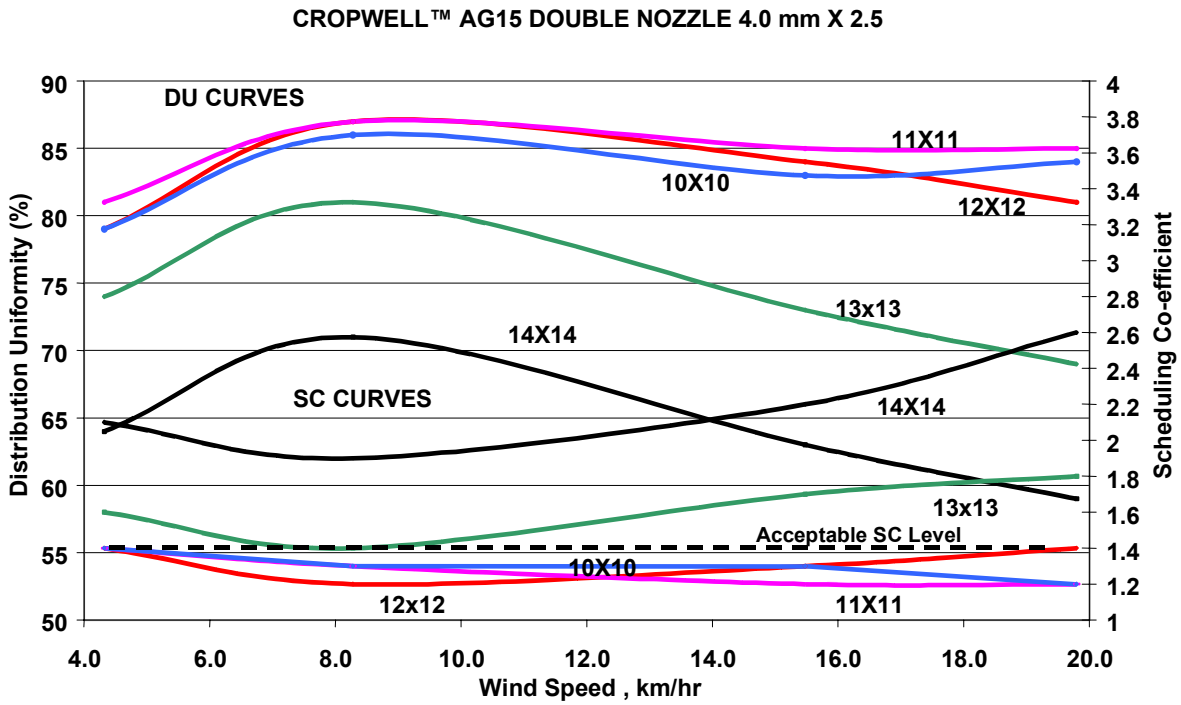


Figure 2.28. Effect of wind on distribution uniformity and scheduling coefficient.

Rectangular configuration

The sprinkler has an acceptable DU for wind speeds up to 20 km/hour when spaced at 9 m x 12 m and 9 m x 14 m. At all other spacing the DU is below 75 per cent (Figure 2.29). The SC's of this sprinkler at spacings of 9 m x 12 m and 9 m x 14 m are below the maximum allowable limit of 1.4 (Figure 2.30).

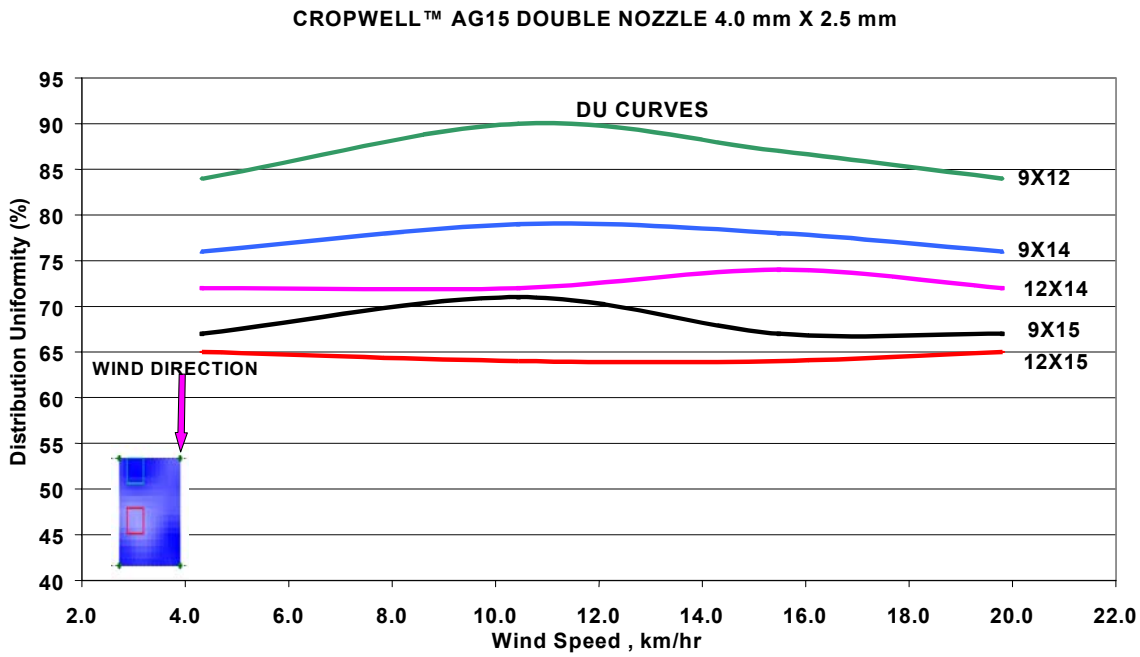


Figure 2.29. Effect of wind on distribution uniformity in rectangular configuration.

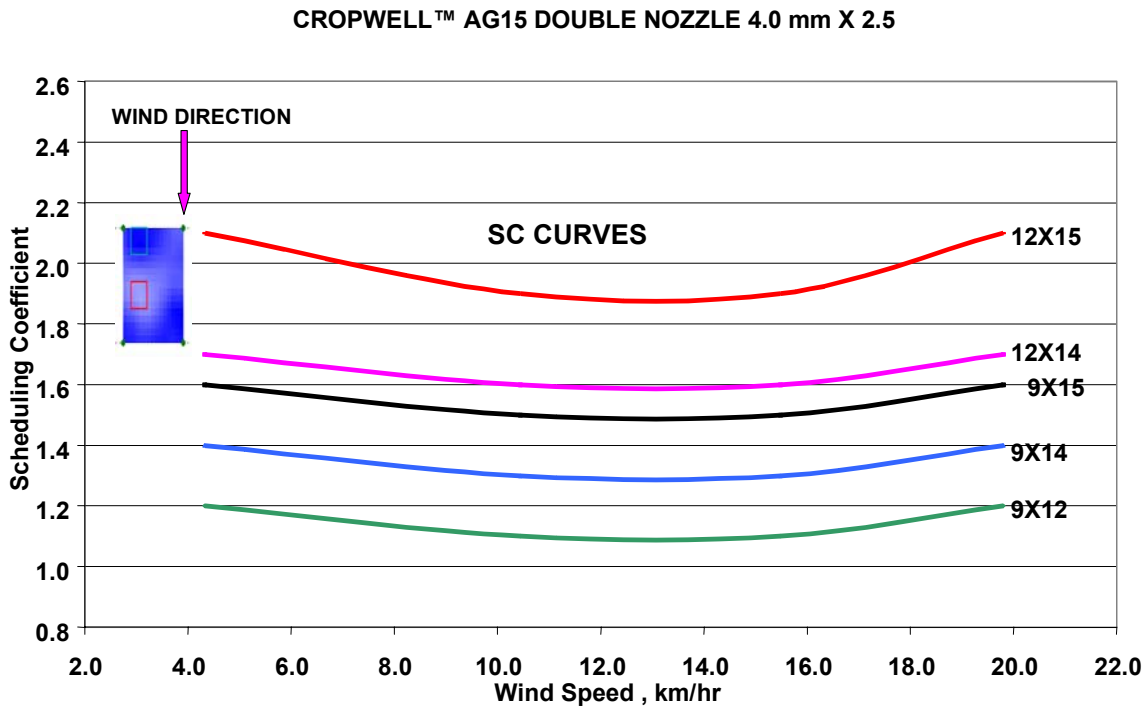


Figure 2.30. Effect of wind on distribution uniformity in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 10 m x 10 m, 11 m x 11 m and 12 m x 12m.
Rectangular configuration: 9 m x 12 m and 9 m x 14 m.

Effect of operating pressure on distribution uniformity

Three additional tests were carried out at operating pressures of 250, 300 and 400 kPa to study the effect of operating pressure on the distribution uniformity (Figure 2.31). The wind speed for these three tests was similar (between 10.8 and 12.2 km/hour). The results show that proper spacing is crucial when pressure is varied within the range recommended by the manufacturer. The distribution uniformity at a spacing of 12 m x 12 m is uniform and above the minimum acceptable level of 75 per cent over the entire pressure range from 250 to 400 kPa. The distribution uniformity at a spacing of 14 m x 14 m decreases from 75 per cent at 250 kPa to as low as 65 per cent when the pressure is above 300 kPa. Figure 2.31 shows that increasing operating pressure to increase radius of throw in an effort to compensate for large spacings does not necessarily achieve better uniformity. It may lead to poorer uniformity at higher speeds due to increased drift of the smaller droplets.

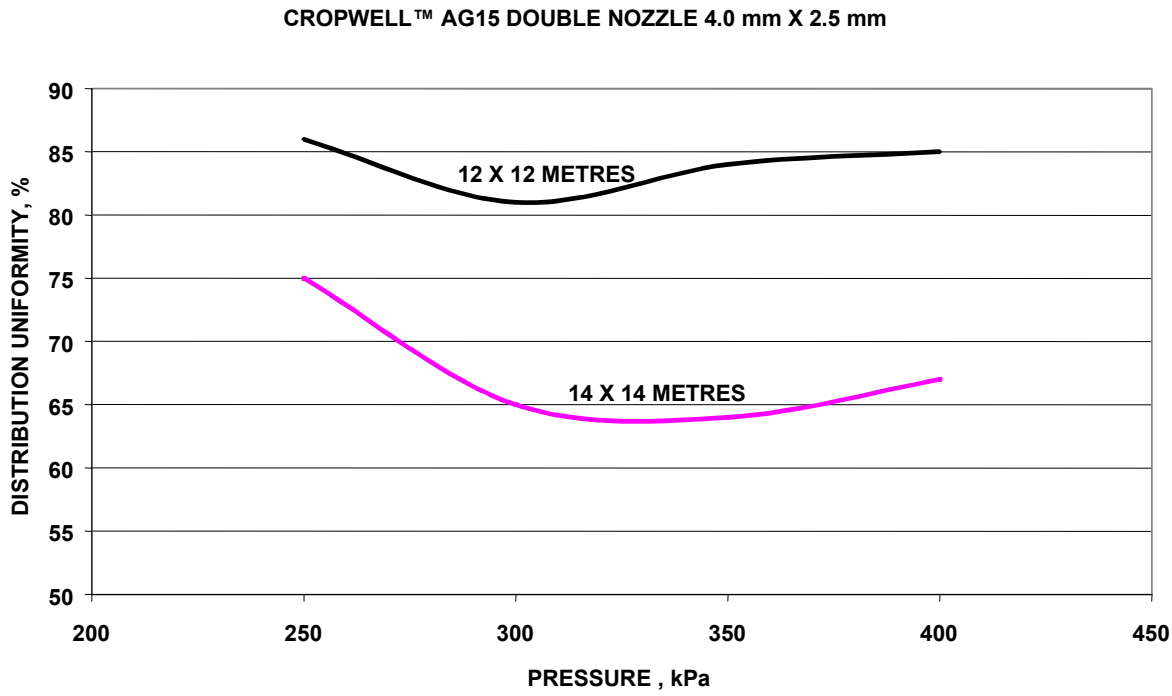


Figure 2.31. Effect of operating pressure on distribution uniformity.

2.3.3 NELSON WINDFIGHTER™

Model: **Nelson Windfighter R2000WF**
Jet size(s): #18 Gold (9/16)
Test pressure: 350 kPa
Flow rate: 15.7 litres/minute
Diameter of throw: 25.0 - 26.2 metres

Results

Ten tests were conducted on the R2000WF #18 Gold sprinkler at an operating pressure of 350 kPa for average wind speeds between 5.8 and 19.1 km/hr. Three tests (149, 150 and 151) were carried out at 200 kPa, 250 kPa and 300 kPa respectively to study the effect of pressure variation on the distribution uniformity. The wind speed data measured during each test on this sprinkler is shown in Table 2.7.

Table 2.7 Prevailing wind speed and wind direction during testing of Nelson Windfighter - Model R2000WF #18 Gold

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
84	12.2	20.5	4.0	1.1	237	24
88	19.1	38.9	7.6	1.6	109	15
99	5.8	15.1	0.4	0.7	209	56
100	7.2	16.6	0.4	1.0	169	38
121	10.1	16.6	4.0	0.9	171	19
149*	11.2	22.7	2.2	1.1	193	20
150*	12.6	23.0	4.7	1.2	200	19
151*	14.4	27.7	5.0	1.3	221	18

* Test Nos. 149, 150 and 151 correspond to operating pressures 200, 250 and 300 kPa respectively.

Square configuration

The DU's for this sprinkler at a 12 m x 12 m and 13 m x 13 m spacing are greater than 75 per cent (minimum acceptable limit) over the range of wind speeds tested. The SC's for these spacings are below the maximum limit of 1.4. The DU at a 14 m x 14 m spacing decreases below 75 per cent and the scheduling coefficient increases above 1.4 as the wind speed increases above 14 km/hr (Figure 2.32).

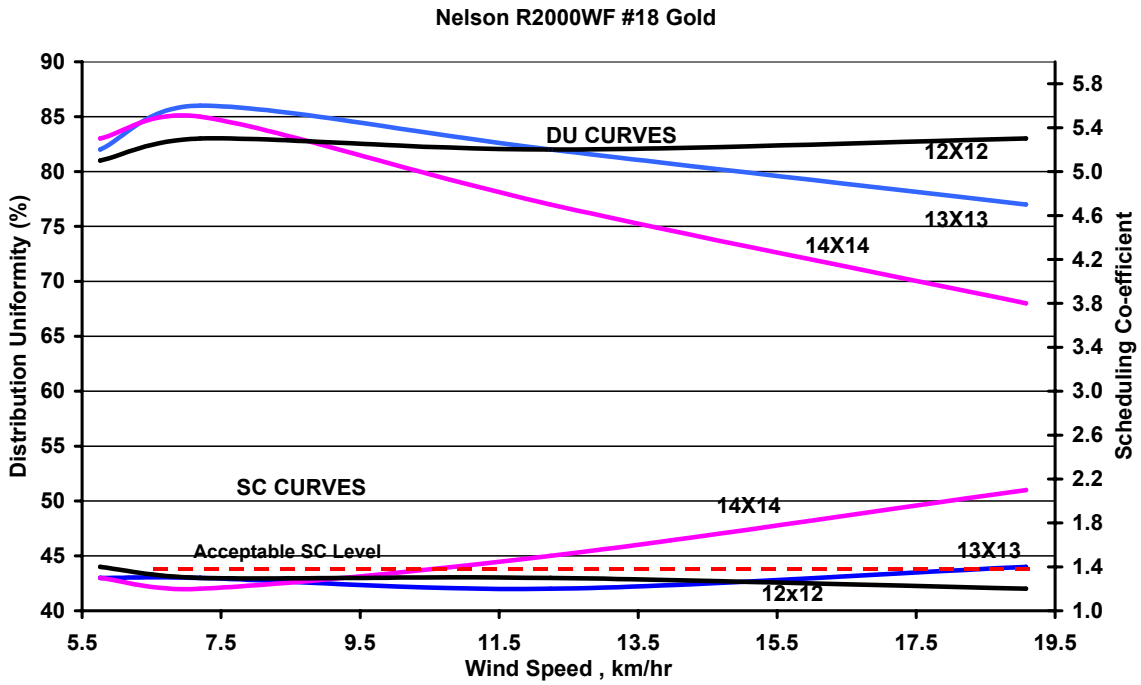


Figure 2.32. Effect of wind on distribution uniformity and scheduling coefficient.

Rectangular configuration

The DU's at 9 m x 12 m and 9 m x 14 m spacings are above 75 per cent (minimum acceptable level) in the wind speed range tested (Figure 2.33). At 12 m x 14 m and 9 m x 15 m the distribution uniformity is acceptable at wind speeds below 17.5 and 15.0 km/hr respectively. For larger spacings (12 m x 15 m, 12 m x 16 m and 14 m x 16 m) the DU is below 75 per cent, except at low wind speeds. The SC is below 1.4 for the 9 m x 12 m and 9 m x 14 m spacings for all wind speeds tested. The SC for the 9 m x 15 m and 12 m x 14 m spacings increases above 1.4 at wind speeds above 15.5 km/hour (Figure 2.34).

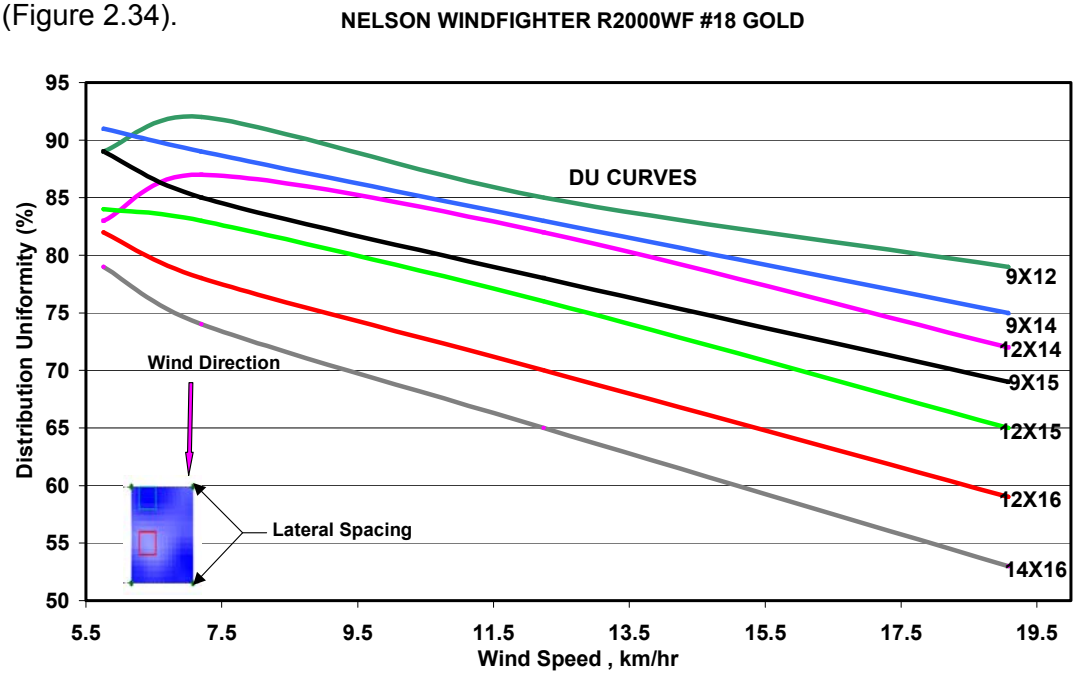


Figure 2.33. Effect of wind speed on distribution uniformity in rectangular configuration.

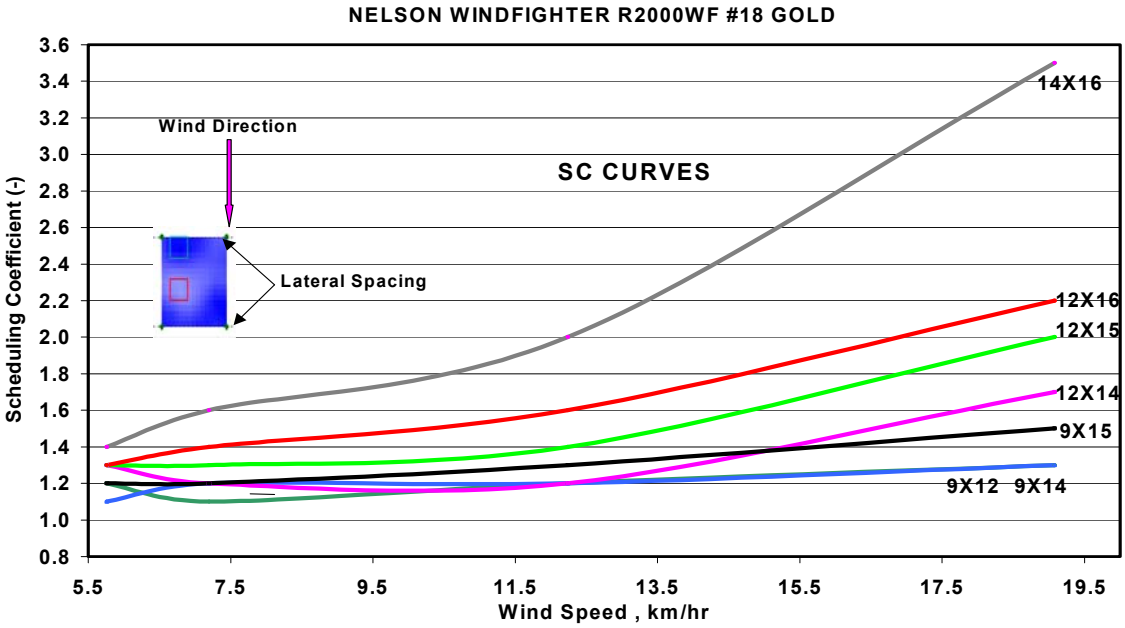


Figure 2.34. Effect of wind speed on distribution uniformity in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m and 13 m x 13 m.
Rectangular configuration: 9 m x 12 m and 9 m x 14 m.

Effect of operating pressure on distribution uniformity

Three additional tests were carried out at operating pressures of 200, 250 and 350 kPa to study the effect of operating pressure on the distribution uniformity (Figure 2.35). The wind speed for these three tests was similar. Reducing the operating pressure from 350 kPa to 200 kPa had little effect on the sprinkler when spaced at 14 m x 14 m. When the sprinklers were spaced at 12 m x 12 m the uniformity dropped slightly as the pressure was decreased to 250 kPa . The uniformity then increased 2.5 per cent at a pressure of 200 kPa.

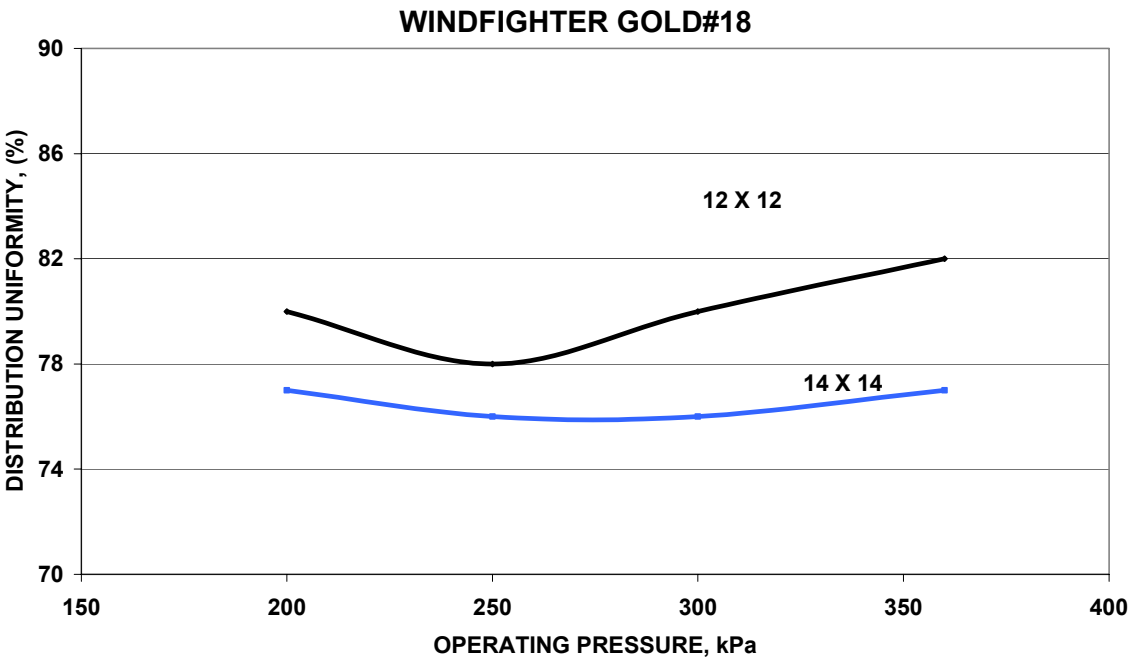


Figure 2.35. Effect of wind speed on distribution uniformity in rectangular configuration.

Model: **Nelson Windfighter R2000WF**
Jet size(s): #16 Red (1/8)
Test pressure: 350 kPa
Flow rate: 12.33 litres/minute
Diameter of throw: 24.4 - 25.6 metres

Results

Seven tests were conducted on the Nelson Windfighter R2000WF #16 Red sprinkler at an operating pressure of 350 kPa for average wind speeds between 7.9 and 13.3 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.8.

Table 2.8 Prevailing wind speed and wind direction during testing of Nelson Windfighter - Model R2000WF #16 Red

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
106	13.3	27.4	4.7	1.2	216	22
109	11.2	19.1	4.0	0.9	238	20
128	10.1	20.5	2.9	1	229	24
132	7.9	23.0	0.0	1.2	142	57
139	12.6	22.7	2.9	1.1	232	19
181	10.4	23.8	2.8	1.0	160	26
206	11.9	22.7	2.9	1.1	168	20

Square configuration

The DU at a 12 m x 12 m spacing was above 75 per cent (minimum acceptable level) for all wind speeds tested. The DU at a 13 m x 13 m spacing decreased below 75 per cent as the wind speed increased above 11 km/hr (Figure 2.36). At a 14 m x 14 m spacing the DU decreased below 75 per cent as the wind speed increased above 9 km/hour and the SC increased above 1.5.

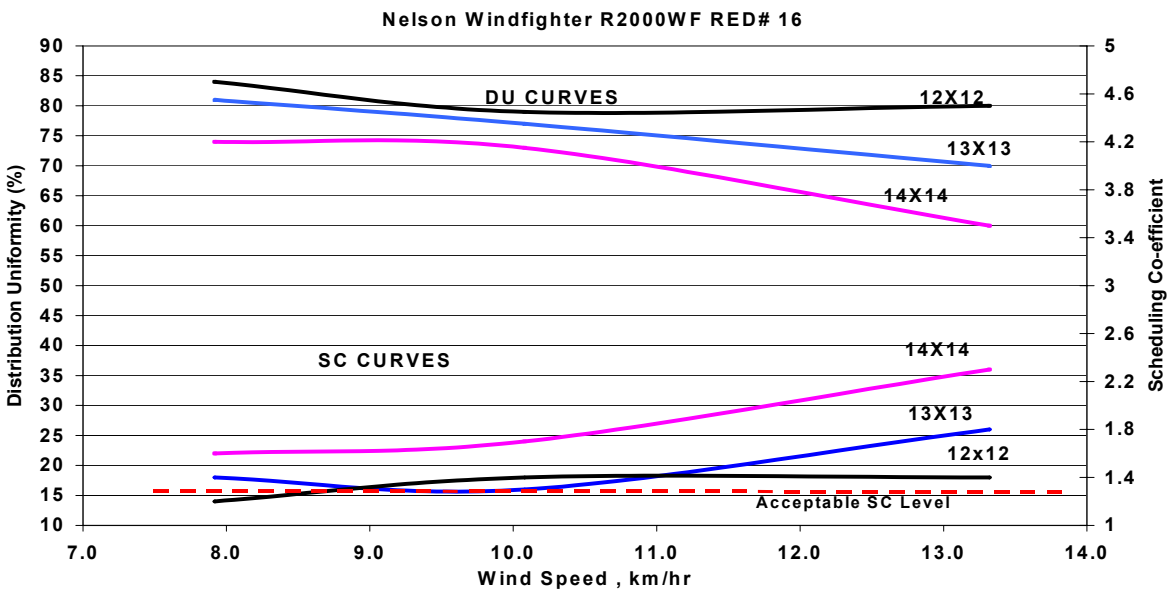


Figure 2.36. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The DU of the Nelson Windfighter R2000WF # 16 at a 9 m x 12 m spacing remained above 75 per cent (minimum acceptable level) and did not decrease as wind speed increased up to 13.5 km/hour (Figure 2.37). The SC at this spacing was below 1.4, the maximum acceptable (Figure 2.38). For all other spacings tested the DU decreased below 75 per cent and the SC increased above 1.4 as the wind speed increased.

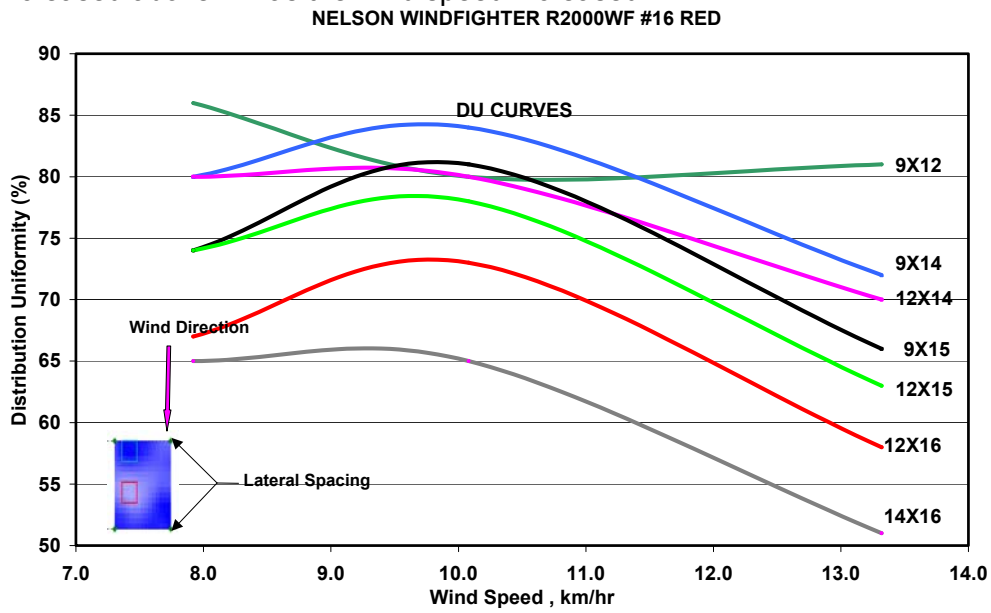


Figure 2.37. Effect of wind speed on distribution uniformity in rectangular configuration.

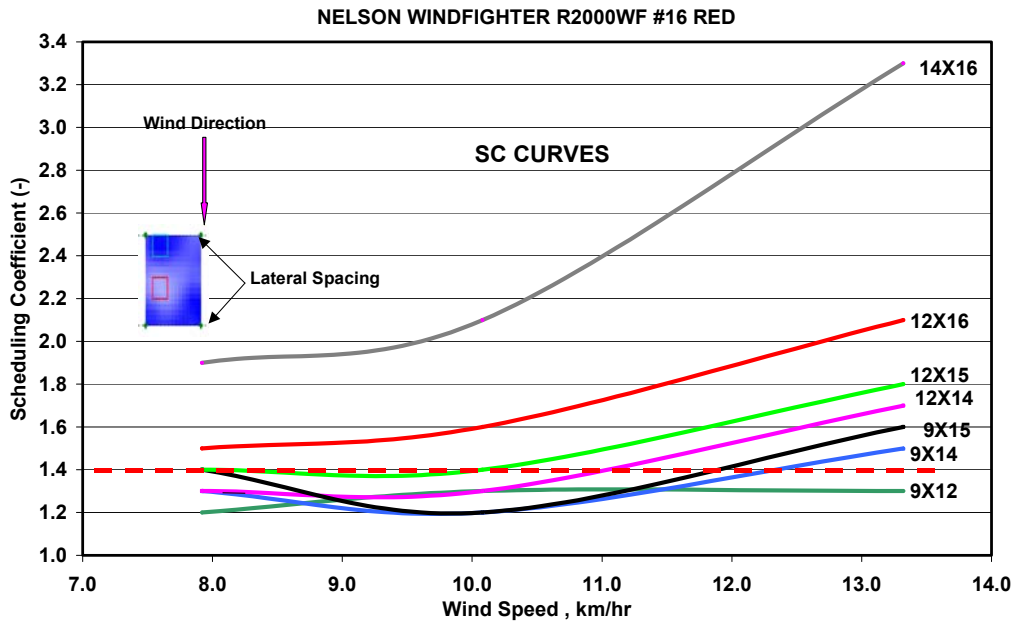


Figure 2.38. Effect of wind speed on scheduling in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m.
Rectangular configuration: 9 m x 12 m.

Model: **Nelson Windfighter R2000WF**
Jet size(s): #14 Green (7/64)
Test pressure: 350 kPa
Flow rate: 9.16 litres/minute
Diameter of throw: 23.8 - 25.0 metres

Results

Seven tests were conducted on the R2000WF #14 Green sprinkler at an operating pressure of 350 kPa for average wind speeds between 6.5 and 13.7 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.9.

Table 2.9 Prevailing wind speed and wind direction during testing of Nelson Windfighter - Model R2000WF #14 Green

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
83	6.5	14.8	1.1	0.8	201	31
101	10.8	22.3	2.5	1.0	241	20
102	13.7	21.6	7.2	1.0	25	8
105	11.2	22.7	2.9	1.1	226	25
136	13.0	22.3	3.6	1.2	129	21
182	10.1	22.3	0.4	1.1	175	24
192	10.8	17.6	5.0	0.8	33	5

Square configuration

The DU at a spacing of 12 m x 12 m was above 75 per cent (accepted minimum level) over the range of wind speeds tested. The DU at all other spacings decreased below 75 per cent in the as wind speed increased (Figure 2.39). The SC at 12 m x 12 m spacing is below 1.4, the maximum acceptable limit.

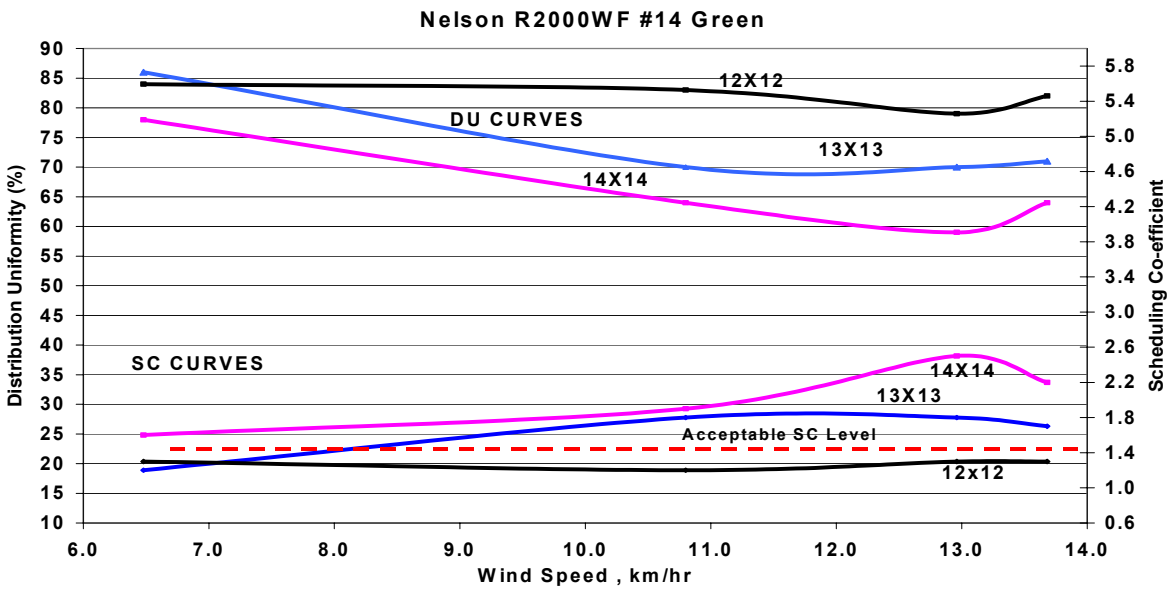


Figure 2.39. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

At a spacing of 9 m x 12 m the Nelson Windfighter R2000WF # 14 had a DU above 75 per cent for all wind speeds tested (Figure 2.40). For all other sprinkler spacings the DU decreased below 75 per cent as wind speed increased. The SC was below 1.4 for all wind speeds when the sprinkler was spaced at 9 m x 12 m (Figure 2.41).

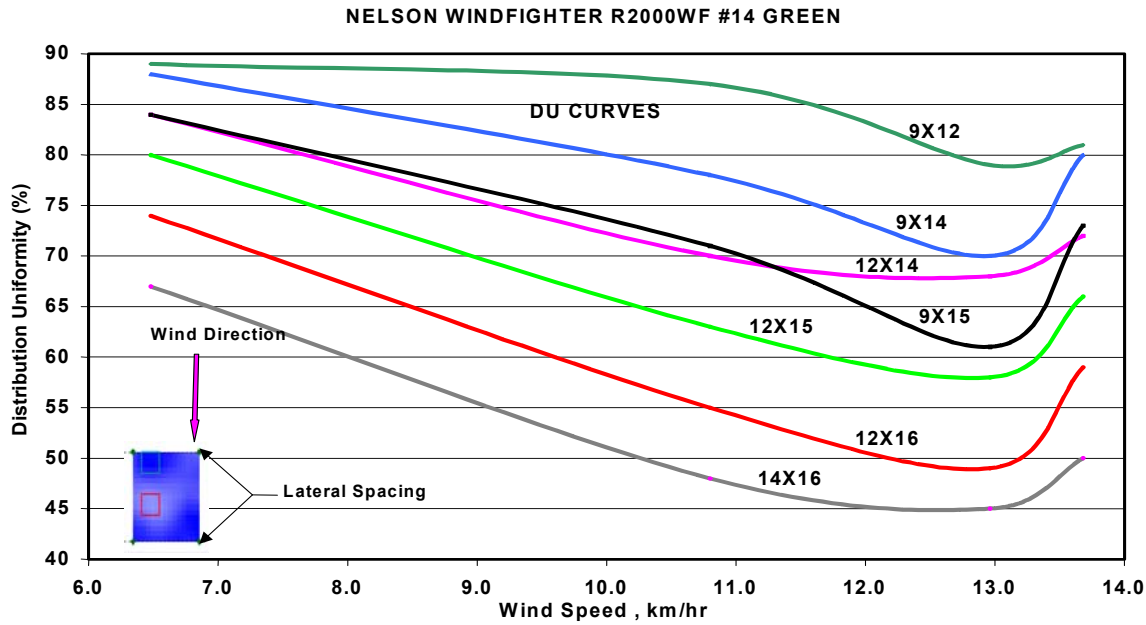


Figure 2.40. Effect of wind speed on distribution uniformity in rectangular configuration.

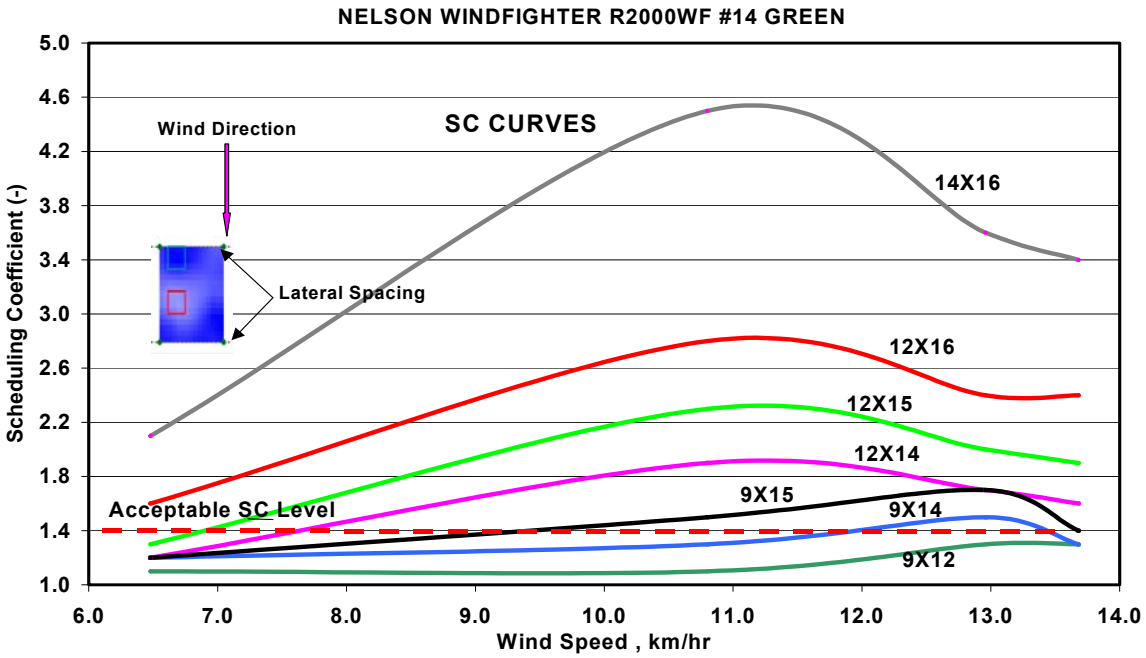


Figure 2.41. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m.
Rectangular configuration: 9 m x 12 m.

2.3.4 NAAN™

Model: **Naan 5024**
Jet size(s): 3.2 mm
Test pressure: 300 kPa
Flow rate: 11.6 litres/minute
Diameter of throw: 21.0 metres

Results

Six tests were conducted on the Naan 5024 sprinkler at an operating pressure of 300 kPa for average wind speeds between 7.2 and 14.8 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.10.

Table 2.10 Prevailing wind speed and wind direction during testing of Naan Model 5024

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
94	7.2	16.2	1.1	0.8	186	21
95	10.4	23.7	4.7	0.8	232	26
103	12.6	23.7	5.0	1.1	12	16
107	8.6	20.2	2.9	0.9	236	30
117	12.6	22.7	6.5	1.0	16	13
197	14.8	26.3	5.0	1.0	193	14

Square configuration

The DU at a spacing of 10 m x 10 m was below 75 per cent (accepted minimum level) over the range of wind speeds tested (Figure 2.42). The SC at 10 m x 10 m spacing was above 1.4 the maximum acceptable limit for all spacings tested.

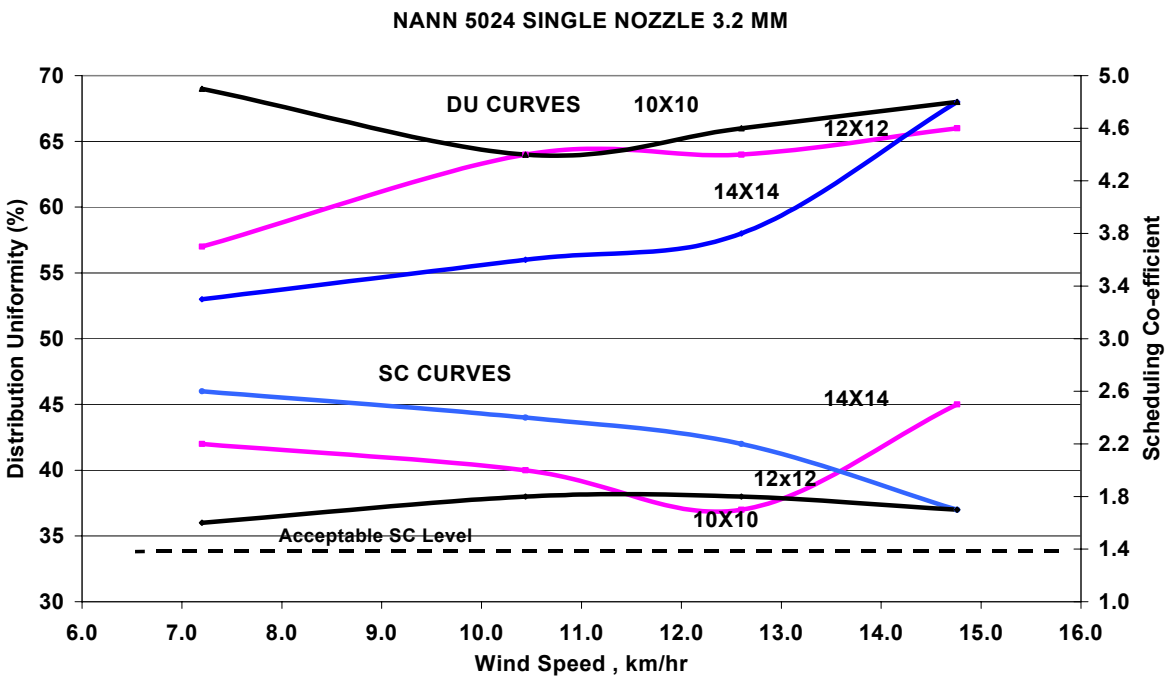


Figure 2.42. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The DU's for this sprinkler at spacings of 9 m x 12 m and 9 m x 14 m are above 75 per cent over the range of wind speeds tested (Figure 2.43). At 9 m x 12 m and 9 m x 14 m spacings this sprinkler has a SC below 1.4 over the range of wind speeds tested (Figure 2.44).

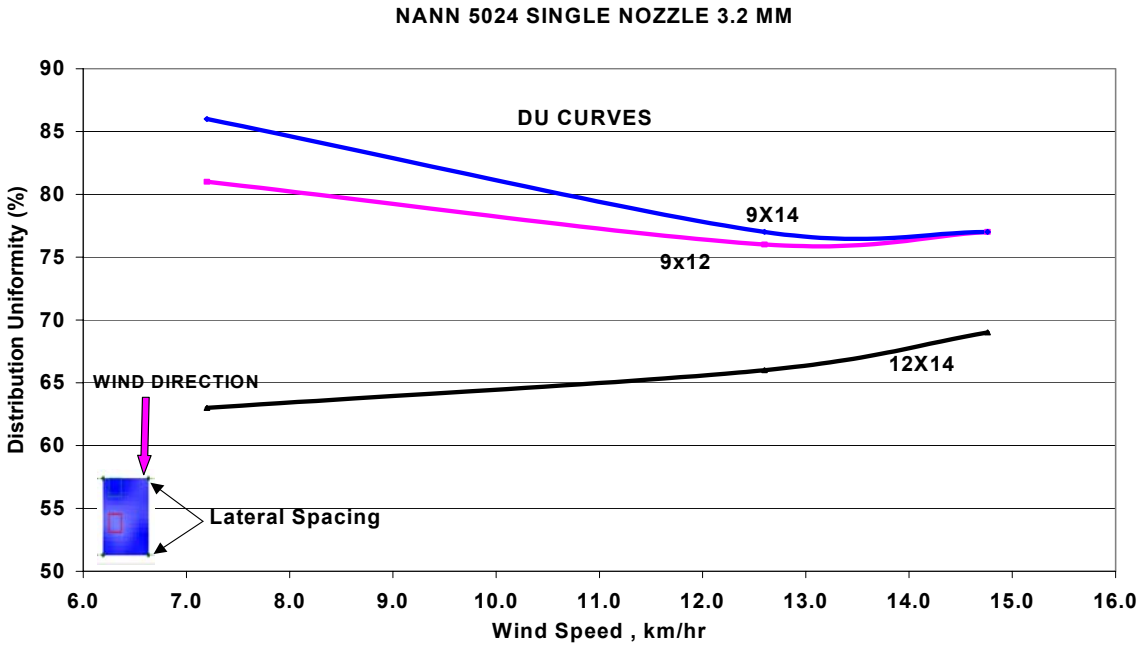


Figure 2.43. Effect of wind speed on distribution uniformity in rectangular configuration.

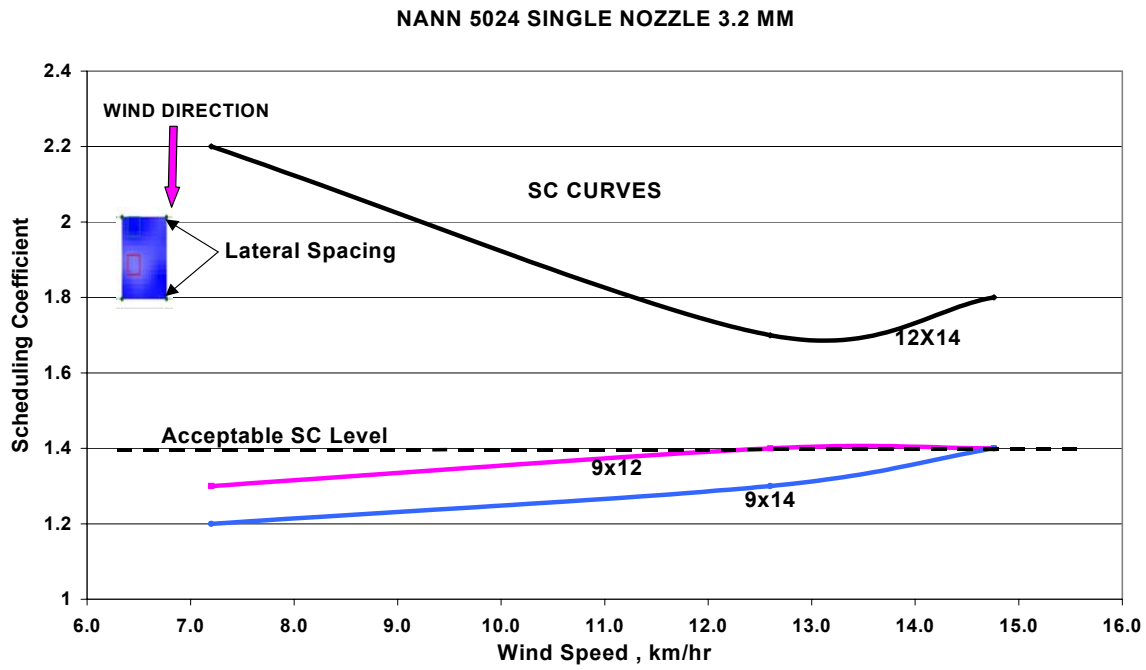


Figure 2.44. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: Not recommended for any of the spacings tested.
Rectangular configuration: 9 m x 12 m and 9 m x 14 m.

Model: **Naan 322**
Jet size(s): 3.5 mm x 2.5 mm
Test pressure: 300 kPa
Flow rate: 19.8 litres/minute
Diameter of throw: 25.0 metres

Results

Eight tests were conducted on the Naan model 322 sprinkler with 3.5 mm and 2.5 mm nozzles at an operating pressure of 300 kPa for average wind speeds between 4.7 and 16.9 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.11.

Table 2.11 Prevailing wind speed and wind direction during testing of Naan Model 322 - double nozzle 3.5 mm x 2.5 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
39	7.6	14.8	2.2	0.7	256	32
40	10.1	19.1	2.9	1.0	242	27
140	10.4	22.3	2.9	1.0	238	23
144	16.9	29.9	5.0	1.3	217	15
164	10.4	24.1	2.2	1.2	164	14
183	16.2	34.9	3.6	1.7	77	17
194	4.7	14.0	0.0	0.6	247	18
205	11.2	20.5	2.9	1.0	125	29

Square configuration

The DU for this sprinkler at 10 m x 10 m and 12 m x 12 m spacings is above the 75 per cent (minimum acceptable level) over the range of wind speeds tested (Figure 2.45). The DU at a 14 m x 14 m spacing falls below 75 per cent as the wind speed increases to greater then 6 km/hour. The SC is below 1.4 (acceptable maximum limit) for spacings of 10 m x 10 m and 12 m x 12 m over the range of wind speeds tested.

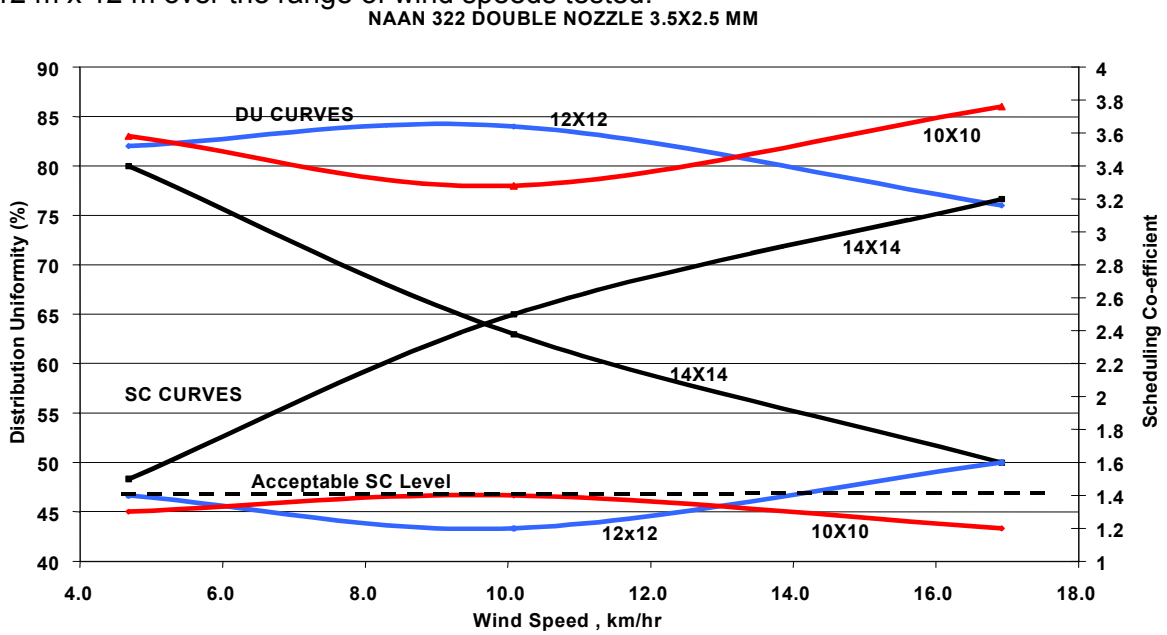


Figure 2.45. Effect of wind speed on distribution and scheduling coefficient.

Rectangular configuration

The DU for this sprinkler is above 75 per cent (minimum acceptable level) at a spacing of 9 m x 12 m for the range of wind speeds tested. At all other spacings the DU decreases below 75 per cent as the wind speed increases (Figure 2.46). The SC is below the maximum acceptable limit of 1.4 at a spacing of 9 m x 12 m only (Figure 2.47).

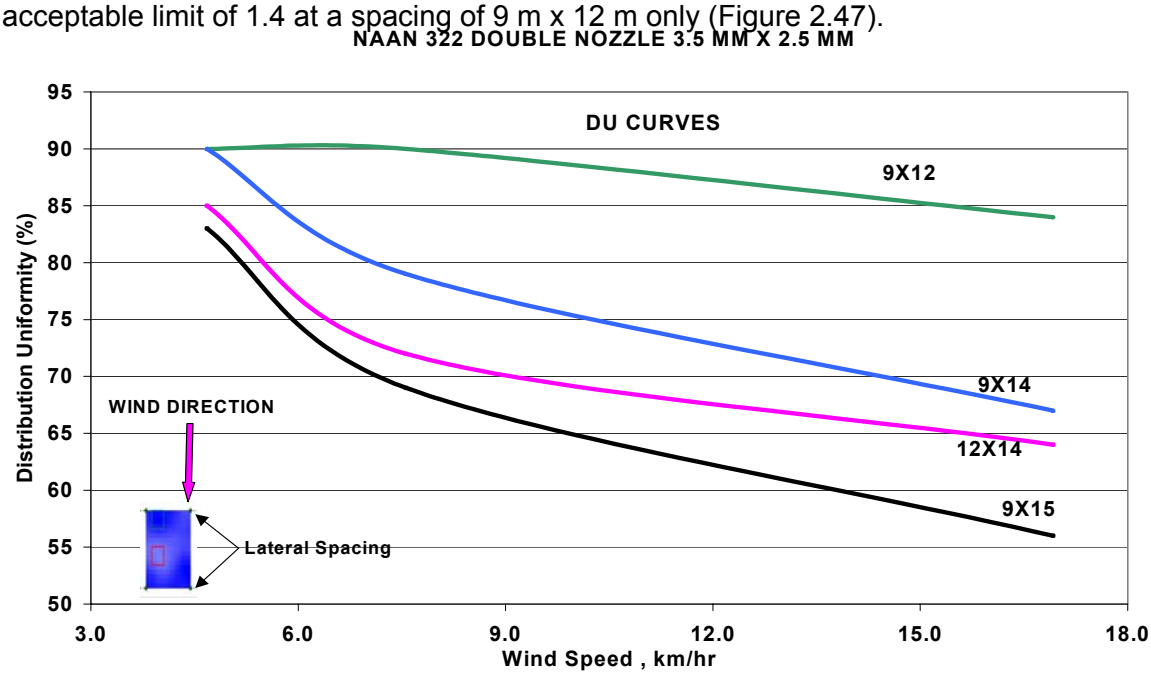


Figure 2.46. Effect of wind speed on distribution uniformity in rectangular configuration.

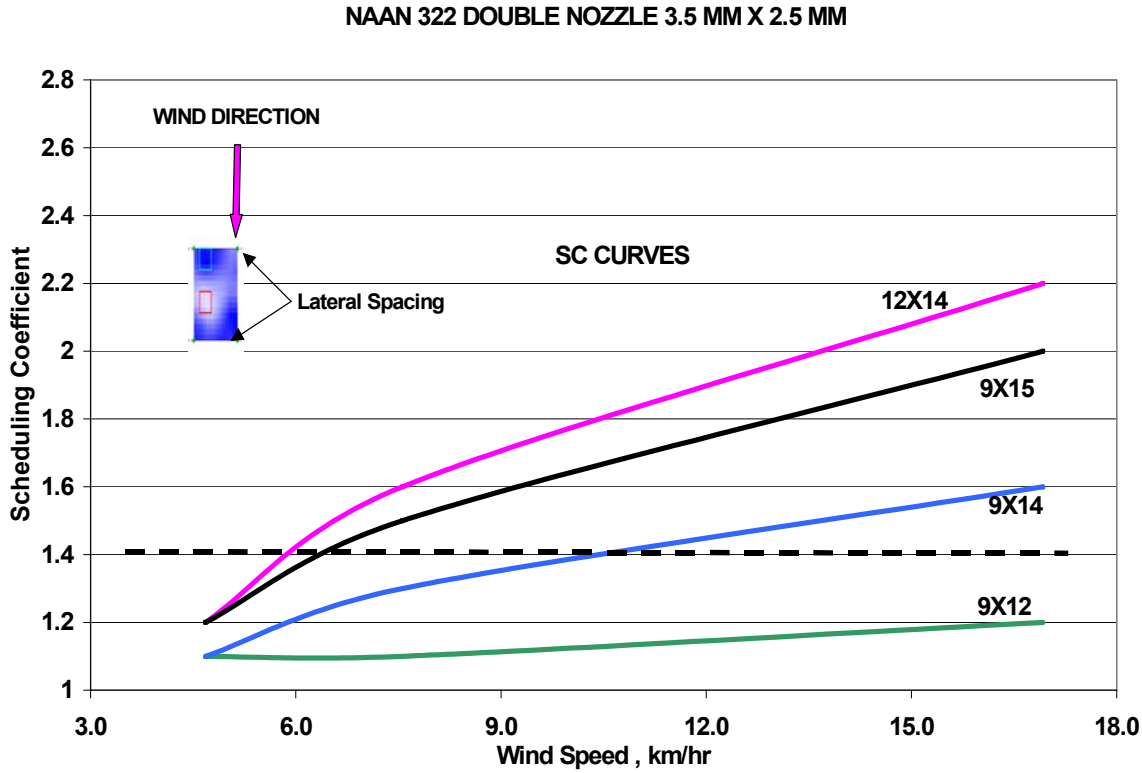


Figure 2.47. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 10 m x 10 m and 12 m x 12 m.
Rectangular configuration: 9 m x 12 m.

Model: **Naan 5035**
Jet size(s): 5.0 mm
Test pressure: 400 kPa
Flow rate: 30.8 litres/minute
Diameter of throw: 31.5 metres

Results

Seven tests were conducted on the Naan model 5035 with a single 5 mm nozzle at an operating pressure of 400 kPa for average wind speeds between 5.4 and 19.8 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.12.

Table 2.12 Prevailing wind speed and wind direction during testing of Naan Model 5035 - single nozzle 5.0 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
26	5.4	10.1	2.2	0.4	276	34
27	7.2	11.2	2.2	0.5	248	22
59	14.0	24.8	4.7	1.1	249	19
60	15.1	29.2	7.2	1.1	217	17
133	11.2	19.8	0.0	1.0	256	33
173	19.8	37.8	6.5	1.6	110	21
204	12.6	23.8	2.9	1.0	115	25

Square configuration

The DU of this sprinkler at a 12 m x 12 m spacing is above the 75 per cent (the minimum acceptable level) at at all wind speeds tested (Figure 2.48). The DU at a spacing of 13 m x 13 m is above 75 per cent at wind speeds below 16 km/hr. At a spacing of 12 m x 12 m the SC is below 1.4 (maximum acceptable limit) for all wind speeds and at a 13 m x 13 m spacing the SC only increases above 1.4 when the wind speed is above 16 km/hour.

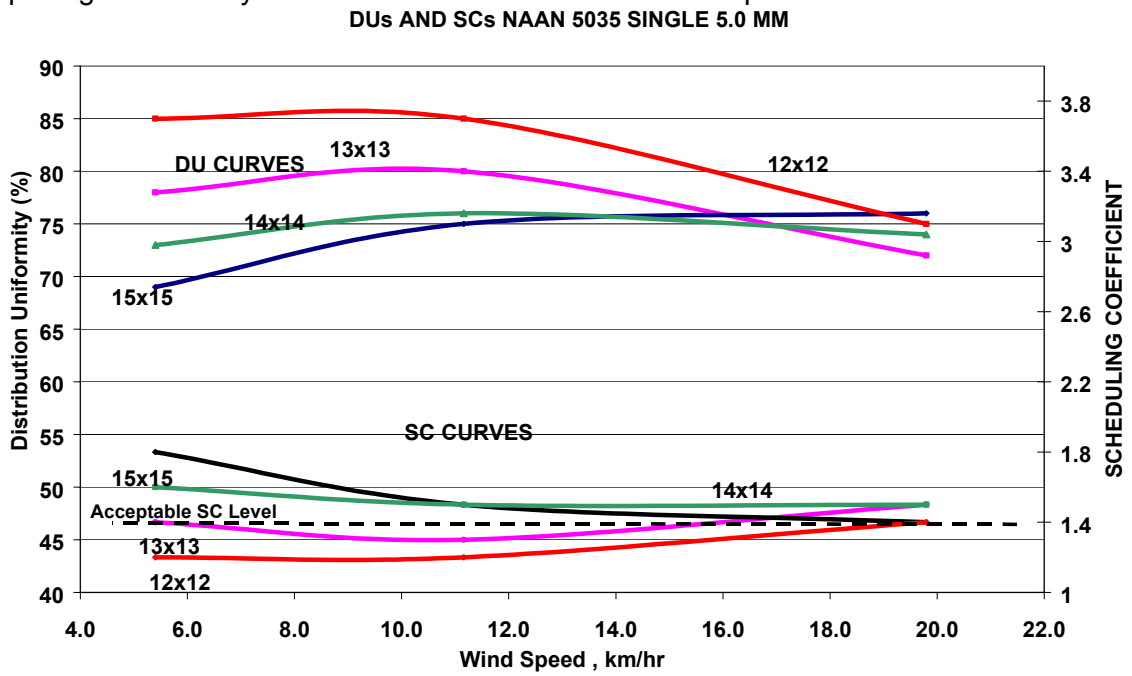


Figure 2.48. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The DU's for this sprinkler at spacings of 9 m x 14 m, 9 m x 15 m, 12 m x 14 m and 12 m x 15 m were above 75 per cent (minimum acceptable limit) for all wind speeds tested (Figure 2.49). The DU's for this sprinkler at spacings of 12 m x 16 m and 14 m x 16 m only decreased below 75 per cent when the wind speed increased above 18 km/hour. The SCs for all spacings except 14 m x 16 m were below 1.4 (maximum accetable limit) over the range of wind speeds tested (Figure 2.50).

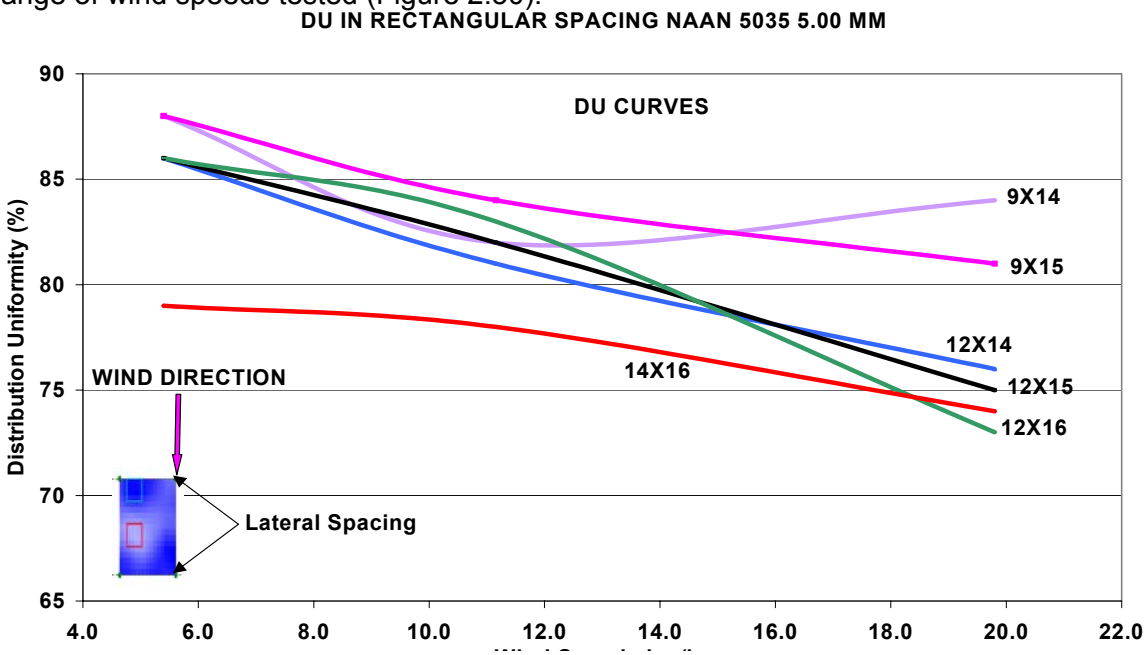


Figure 2.49. Effect of wind speed on distribution uniformity in rectangular configuration.

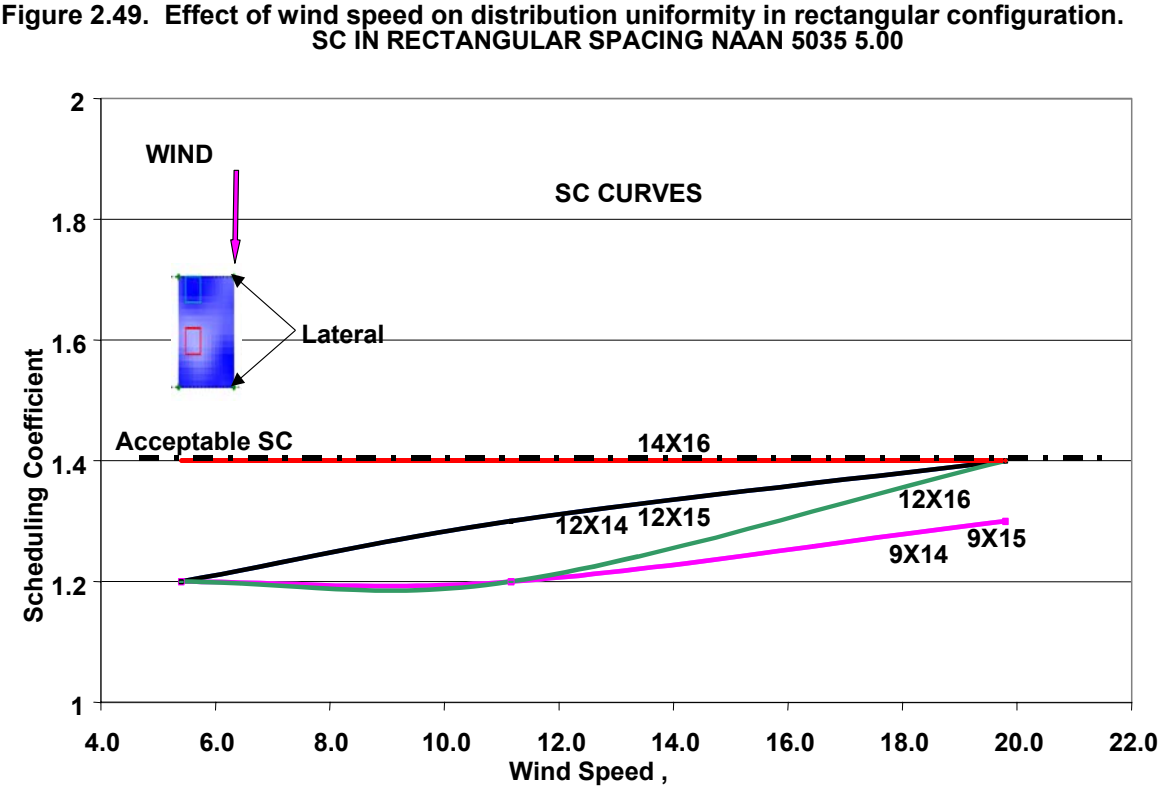


Figure 2.50. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m.

Rectangular configuration: 9 m x 14 m, 9 m x 15 m, 12 m x 14 m and 12 m x 15 m.

Model: **Naan 5035**
Jet size(s): 5.0 mm x 2.5 mm
Test pressure: 400 kPa
Flow rate: 37.5 litres/minute
Diameter of throw: 31.5 metres

Results

Eight tests were conducted on the Naan 5035 double nozzle sprinkler at an operating pressure of 400 kPa for average wind speeds between 3.0 and 21.0 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.13.

Table 2.13 Prevailing wind speed and wind direction during testing of Naan Model 5035 - double nozzle 5.0 mm x 2.5 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
24	3.2	7.6	0.0	0.5	98	18
28	20.9	35.3	8.6	1.7	82	13
29	17.3	30.6	5.4	1.4	88	20
61	16.2	35.3	6.5	1.4	225	20
82	6.8	15.5	0.0	1.0	144	41
115	13.7	21.2	5.4	1.0	25	10
126	11.9	20.5	4.0	0.9	216	20
186	8.3	18.0	1.4	1.0	113	46

Square configuration

The Naan 5035 double nozzle 5.0 mm x 2.5 mm sprinkler had a DU above 75 per cent (minimum acceptable level) for spacings of 12 m x 12 m, 14 m x 14 m and 15 m x 15 m over the range of wind speeds tested. The SC was below the maximum acceptable limit of 1.4 for spacings of 12 m x 12 m and 14 m x 14 m. When spaced at 15 m x 15 m the SC increased above 1.4 when the wind speed increased above 15 km/hour (Figure 2.51).

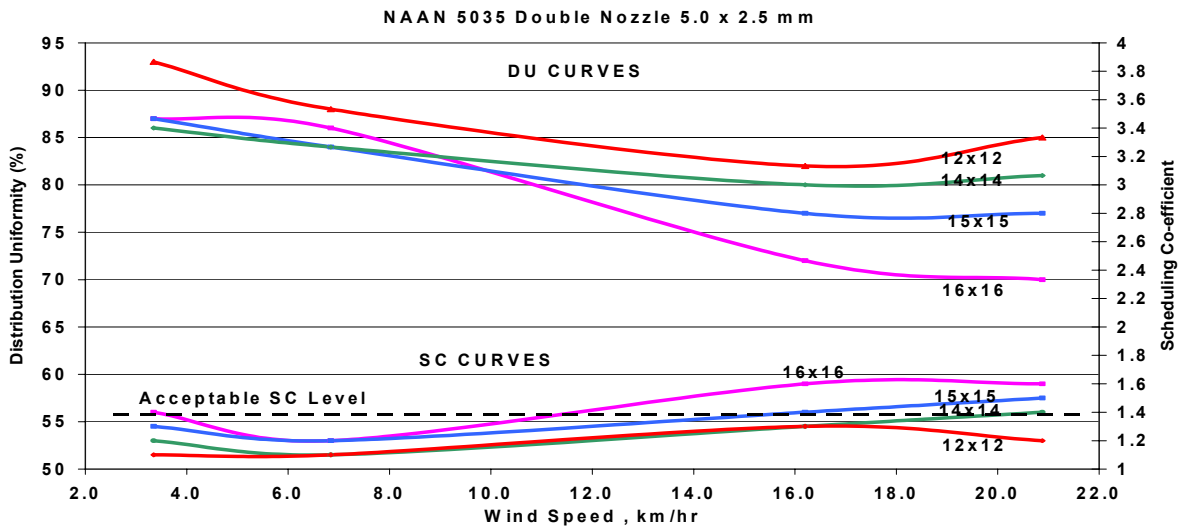


Figure 2.51. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The DU for this sprinkler at rectangular spacings was above 75 per cent for all spacings from 9 m x 12 m to 12 m x 15 m over the range of wind speeds tested. The DU at 12 m x 16 m and 14 m x 16 m decreased below 75 per cent when the wind speed increased above 16 km/hr (Figure 2.52). The SC was below 1.4 (maximum allowable limit) for all spacings except for 12 m x 15 m and 14 m x 16 m (Figure 2.53).

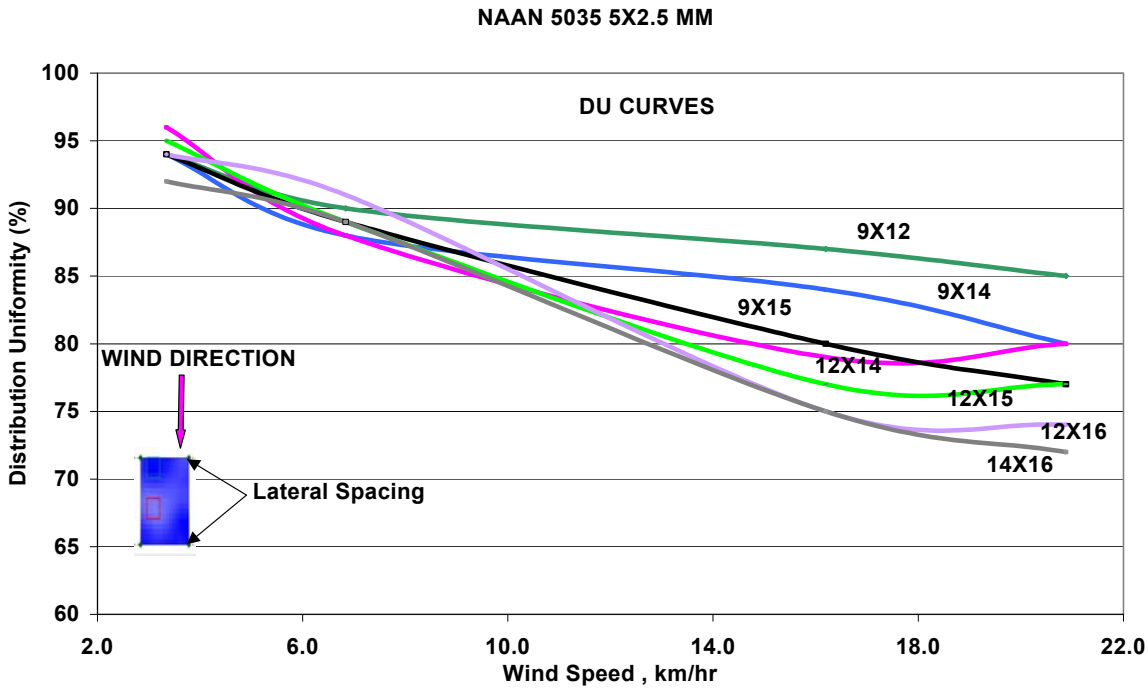


Figure 2.52. Effect of wind speed on distribution uniformity in rectangular configuration.

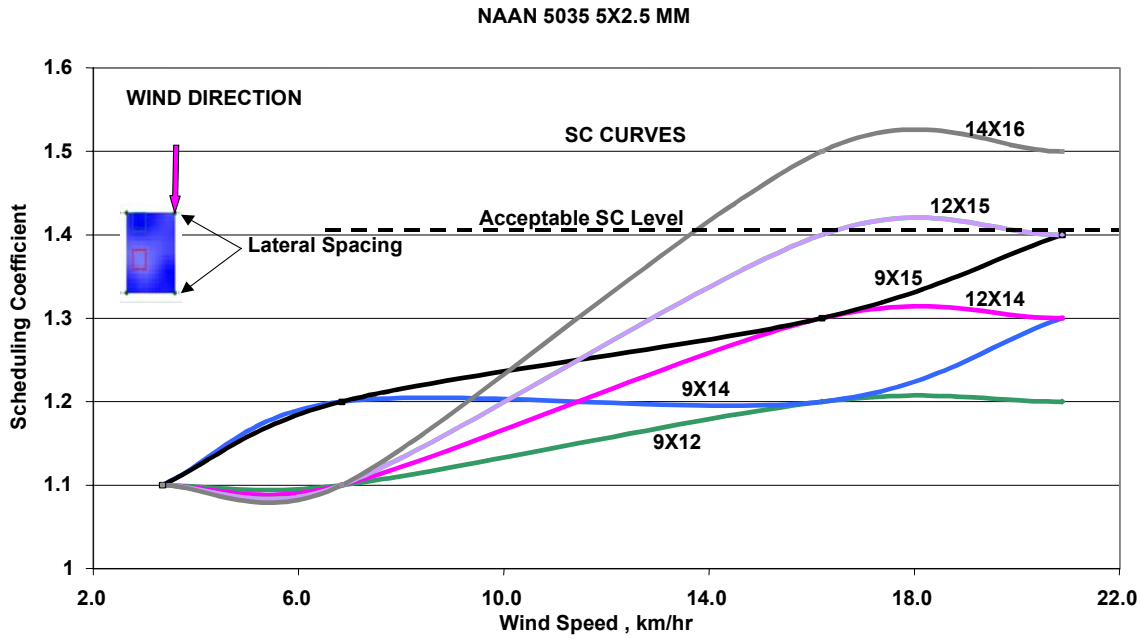


Figure 2.53. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m and 14 m x 14 m.
Rectangular configuration: 9 m x 12 m, 9 m x 14 m, 9 m x 15 m and 12 m x 14 m.

2.3.5 RAINBIRD™

Model: **Rainbird 20J**
Jet size(s): 3.97 mm
Test pressure: 350 kPa
Flow rate: 19.2 litres/minute
Diameter of throw: 24.6 metres

Results

Seven tests were conducted on the Rainbird 20J single nozzle sprinkler at an operating pressure of 350 kPa for average wind speeds between 4.7 and 23.0 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.14.

Table 2.14 Prevailing wind speed and wind direction during testing of Rainbird Model 20J - single nozzle 3.97 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
6	4.7	11.5	0.0	0.7	247	24
9	10.4	21.6	0.4	1.1	261	30
22	16.6	28.8	2.9	1.4	96	18
134	12.6	25.2	4.7	1.2	136	22
135	13.3	25.2	2.5	1.2	126	23
158	10.4	21.2	2.2	1.2	133	22
171	23.0	38.2	6.1	1.6	103	15

Square configuration

The Rainbird 20J single nozzle 3.97 mm at a spacing of 10 m x 10 m has a DU above 75 per cent (minimum acceptable level) over the range of wind speeds tested (Figure 2.54). At a spacing of 12 m x 12 m the DU decreases below 75 per cent and the SC increases above 1.4 (maximum acceptable limit) as the wind speed increases over 12 km/hour.

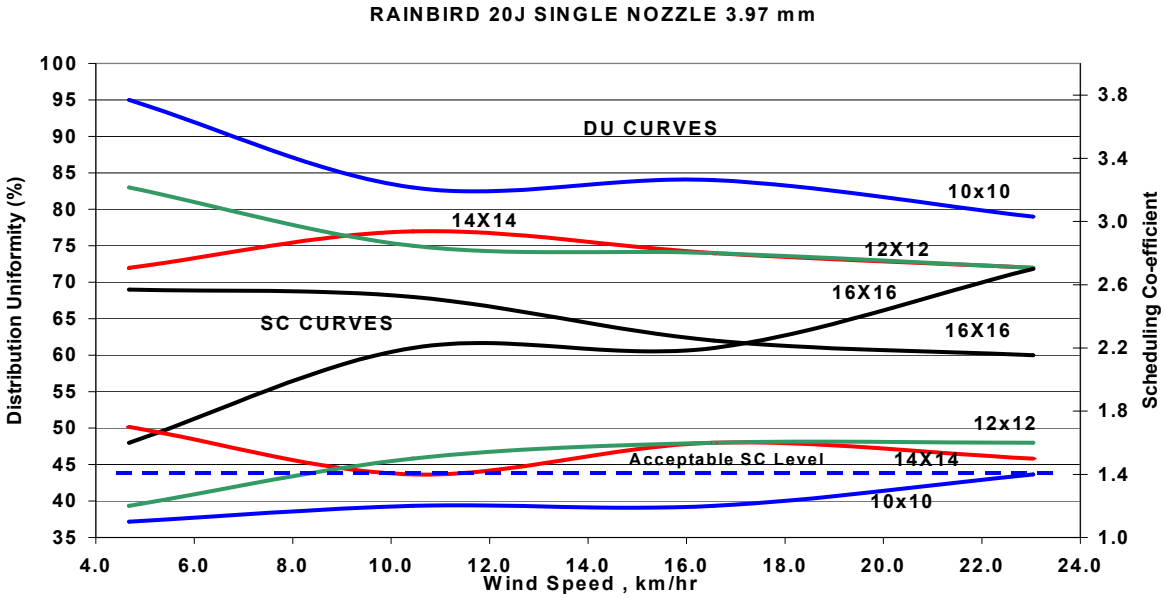


Figure 2.54. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The DU for the Rainbird 20J single nozzle at a spacing of 9 m x 12 m is above 75 per cent (the minimum acceptable limit) and the SC is below 1.4 (maximum allowable limit) for all wind speeds tested (Figures 2.55 and 2.56). At a spacing of 9 m x 14 m this sprinkler has an acceptable DU and SC for wind speeds below 20 km/hr. When spaced at 12 m x 14 m this sprinkler had an acceptable uniformity for wind speeds up to 16 km/hour. At all other spacings the DU is unacceptable even at low wind speeds.

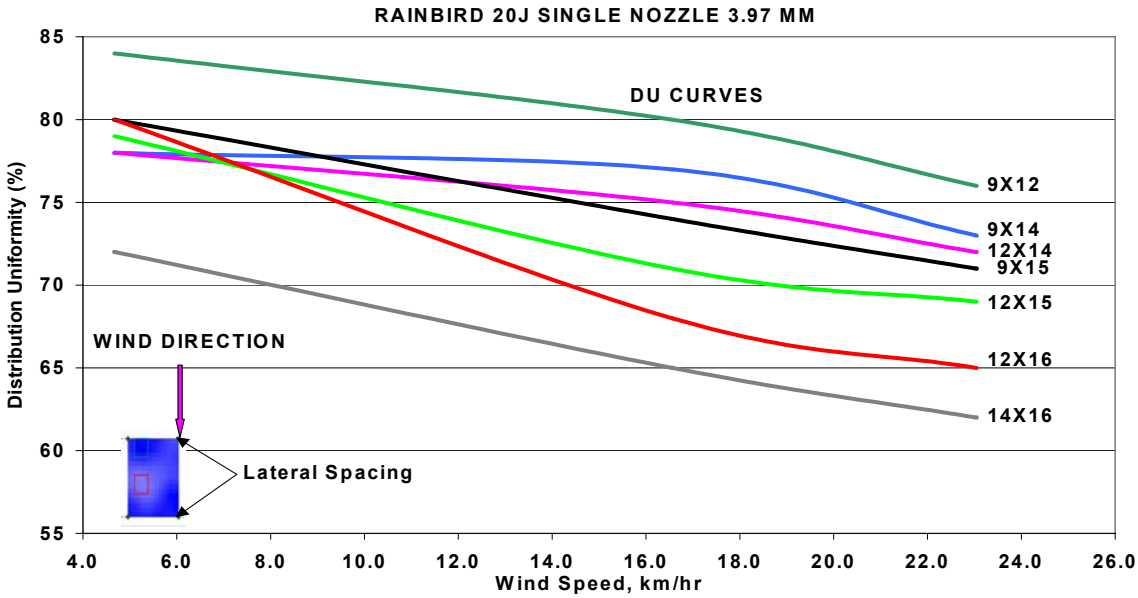


Figure 2.55. Effect of wind speed on distribution uniformity in rectangular configuration.

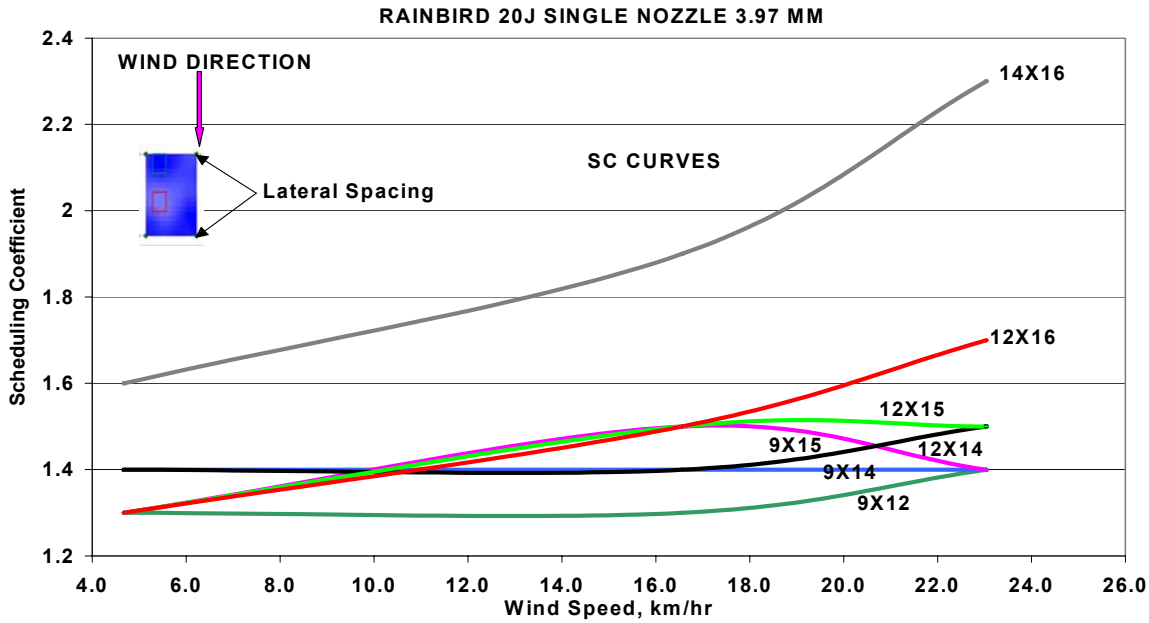


Figure 2.56. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m.
Rectangular configuration: 9 m x 12 m and possibly 9 m x 14 m.

Model: **Rainbird 30BH**
Jet size(s): 3.97 mm x 2.38 mm
Test pressure: 400 kPa
Flow rate: 27.6 litres/minute
Diameter of throw: 27.8 metres

Results

Five tests were conducted on the Rainbird 30BH double nozzle sprinkler at an operating pressure of 400 kPa for average wind speeds between 7.2 and 19.8 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.15.

Table 2.15 Prevailing wind speed and wind direction during testing of Rainbird Model 30BH - double nozzle 3.97 mm x 2.38 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
7	7.2	18.0	0.0	1.0	284	30
8	9.7	19.1	2.2	1.2	276	25
23	14.0	32.4	3.6	1.4	90	23
154	12.2	23.0	2.5	1.1	235	23
172	19.8	36.7	7.6	1.7	101	21

Square configuration

This sprinkler when spaced at 12 m x 12 m has a DU above 75 per cent (minimum acceptable level) for wind speeds up to 18 km/hour (Figure 2.57). At a spacing of 14 m x 14 m the SC increases above 1.4 (maximum acceptable limit) as the wind speed increases over 14 km/hour. At a spacing of 15 m x 15 m this sprinkler has an unacceptable uniformity at all wind speeds tested.

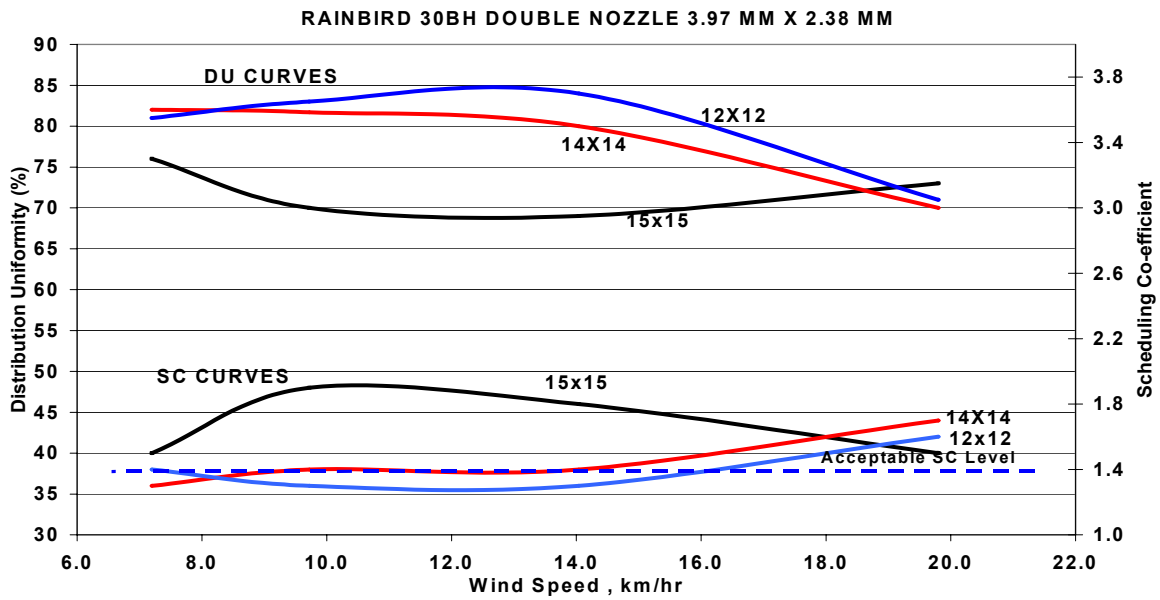


Figure 2.57. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The DU's for the Rainbird 30BH double nozzle at spacings of 9 m x 14 m and 9 m x 15 m are above 75 per cent (the minimum acceptable limit) and the SC is below 1.4 (maximum acceptable limit) for all wind speeds tested (Figures 2.58 and 2.59). At a spacing of 12 m x 14 m the DU is acceptable at all wind speeds tested though the SC is marginal for wind speeds above 10 km/hr. At all other spacings the DU is unacceptable at low wind speeds.

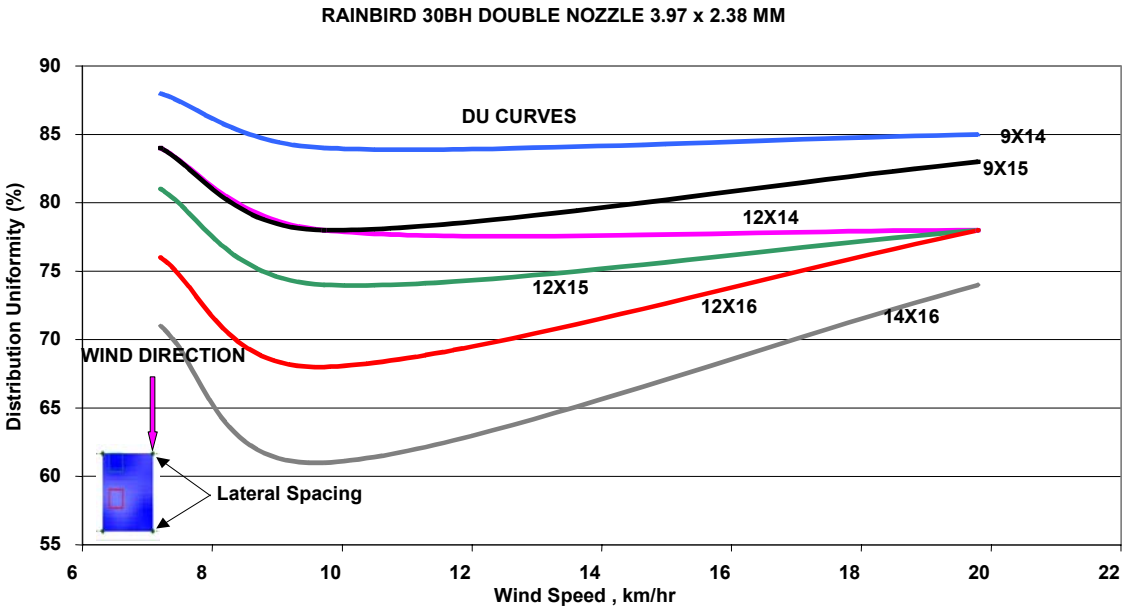


Figure 2.58. Effect of wind speed on distribution uniformity in rectangular configuration.

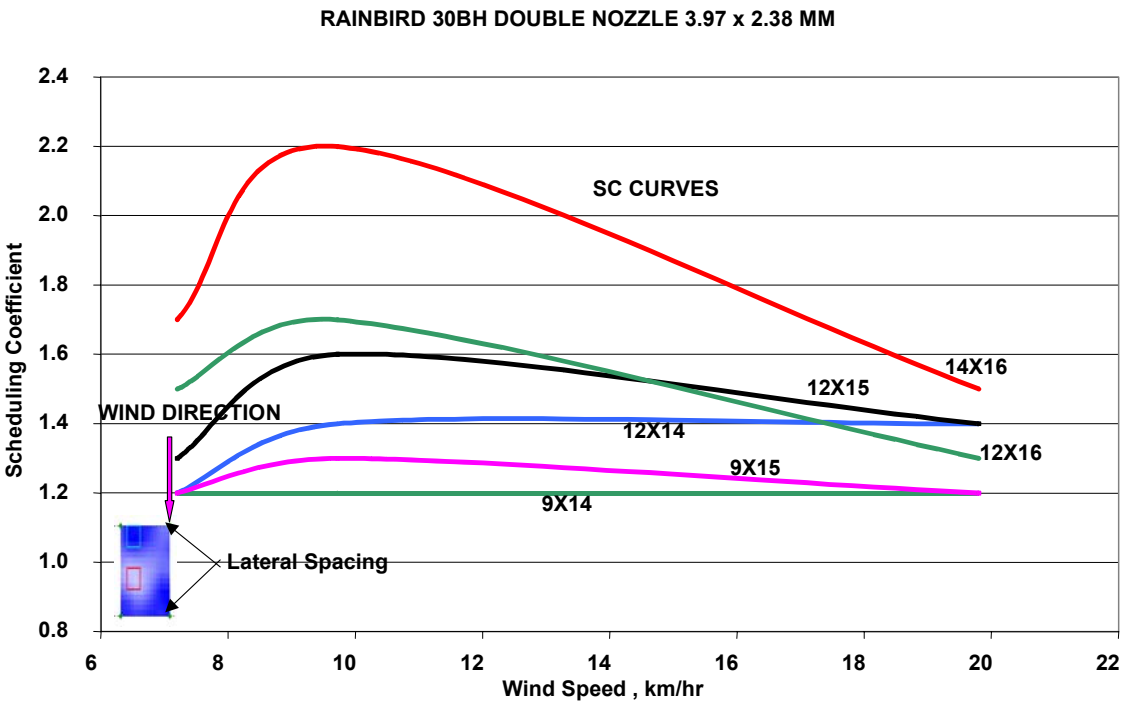


Figure 2.59. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m.
Rectangular configuration: 9 m x 14 m, 9 m x 15 m and possibly 12 m x 14m.

Model: **Rainbird 30BH**
Jet size(s): 4.76 mm x 3.17 mm
Test pressure: 400 kPa
Flow rate: 42.6 litres/minute
Diameter of throw: 31.2 metres

Results

Five tests were conducted on the Rainbird 30BH double nozzle (4.76 mm x 3.17 mm) sprinkler at an operating pressure of 400 kPa for average wind speeds between 7.6 and 17.3 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.16.

Table 2.16 Prevailing wind speed and wind direction during testing of Rainbird Model 30BH - double nozzle 4.76 mm x 3.17 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
52	7.6	18.0	0.0	1.1	104	51
82	11.9	24.1	5.0	1.0	235	27
146	17.3	33.1	6.5	1.4	216	15
162	9.4	19.1	0.0	1.2	132	71
202	14.8	28.8	2.9	1.4	111	22

Square configuration

The Rainbird 30 BH double nozzle 4.76 mm x 3.17 mm when spaced at 12 m x12 m and 13 m x 13 m had a DU above 75 per cent (acceptable minimum level) and a SC below 1.4 (acceptable maximum level) over the range of wind speeds tested (Figure 2.60). When spaced at 14 m x 14 m and 15 m x 15 m this sprinkler had an acceptable uniformity for wind speeds up to 16 km/ hour.

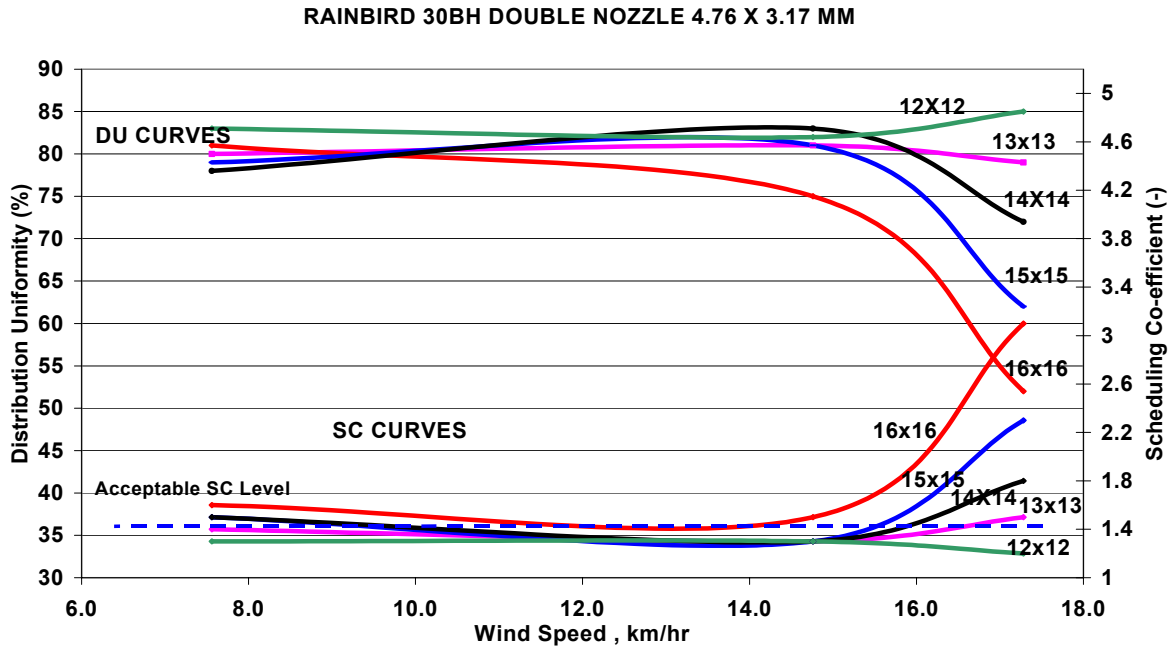


Figure 2.60. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The DU's for the Rainbird 30BH double nozzle at spacings of 9 m x 14 m and 12 m x 14 m are above 75 per cent (the minimum acceptable limit) and the SC is below 1.4 (maximum allowable limit) for all wind speeds tested (Figures 2.61 and 2.62). When spaced at 12 m x 15 m and 12 m x 16 m this sprinkler had an acceptable uniformity for wind speeds up to 16 km/hour.

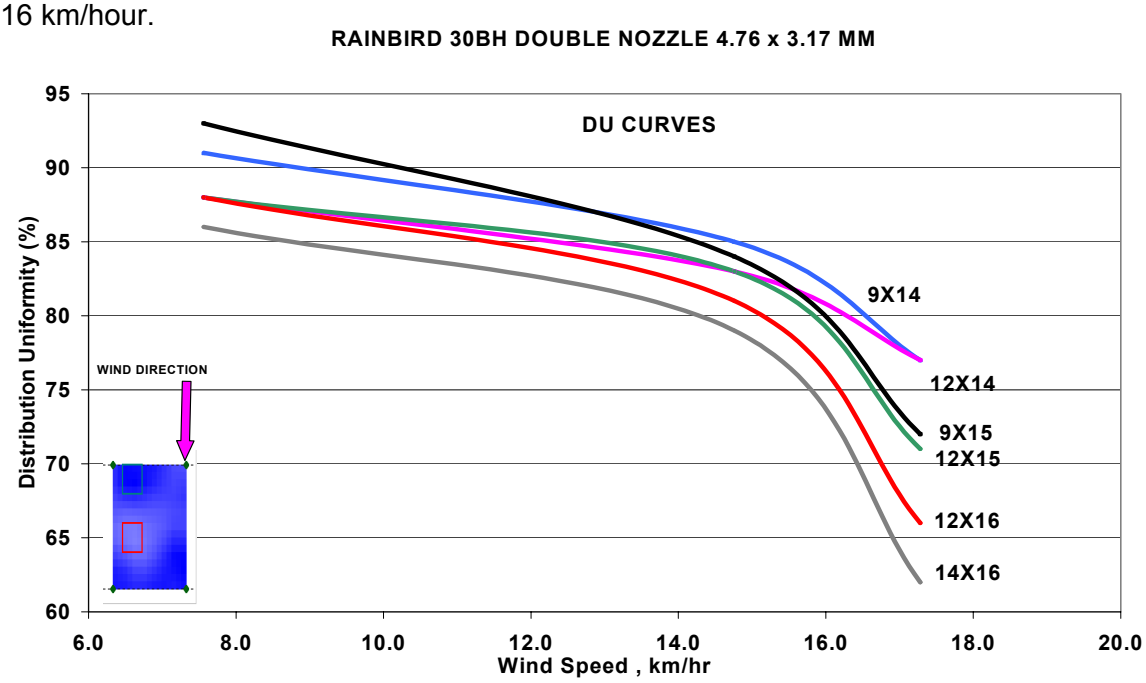


Figure 2.61. Effect of wind speed on distribution uniformity in rectangular configuration.

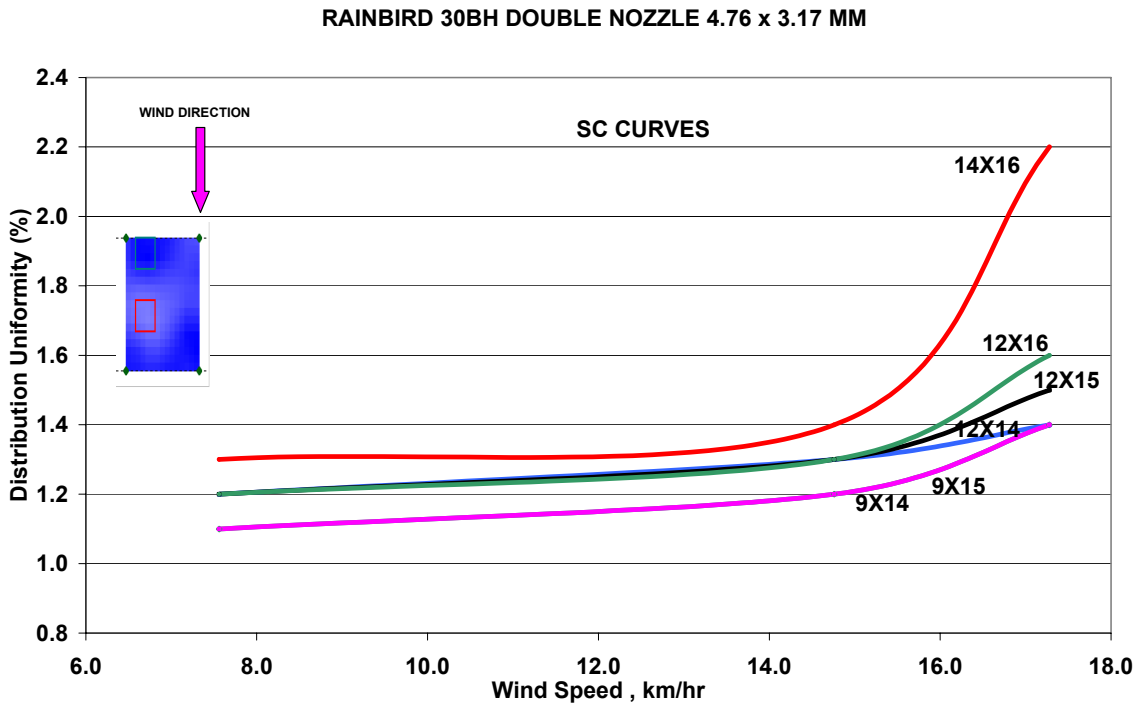


Figure 2.62. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m and 13 m x 13 m.
Rectangular configuration: 9 m x 14 m and 12 m x 14m.

Model: **Rainbird 48H**
Jet size(s): 5.2 mm
Test pressure: 400 kPa
Flow rate: 37.8 litres/minute
Diameter of throw: 36.8 metres

Results

Five tests were conducted on the Rainbird 48H single nozzle sprinkler at an operating pressure of 400 kPa for average wind speeds between 7.2 and 16.2 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.17.

Table 2.17 Prevailing wind speed and wind direction during testing of Rainbird Model 48H - single nozzle 5.2 mm

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
116	16.2	26.3	6.5	1.1	23	10
118	9.7	17.6	2.9	0.8	255	27
125	7.2	14.8	1.1	0.8	256	38
141	12.2	28.1	3.6	1.2	220	20
203	13.3	27.4	2.9	1.3	117	29

Square configuration

The Rainbird 48H single nozzle 5.2 mm when spaced at 12 m x 12 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) for wind speeds below 14 km/hour (Figure 2.63). At all other spacings tested the DU was below 75 per cent and the SC above 1.4.

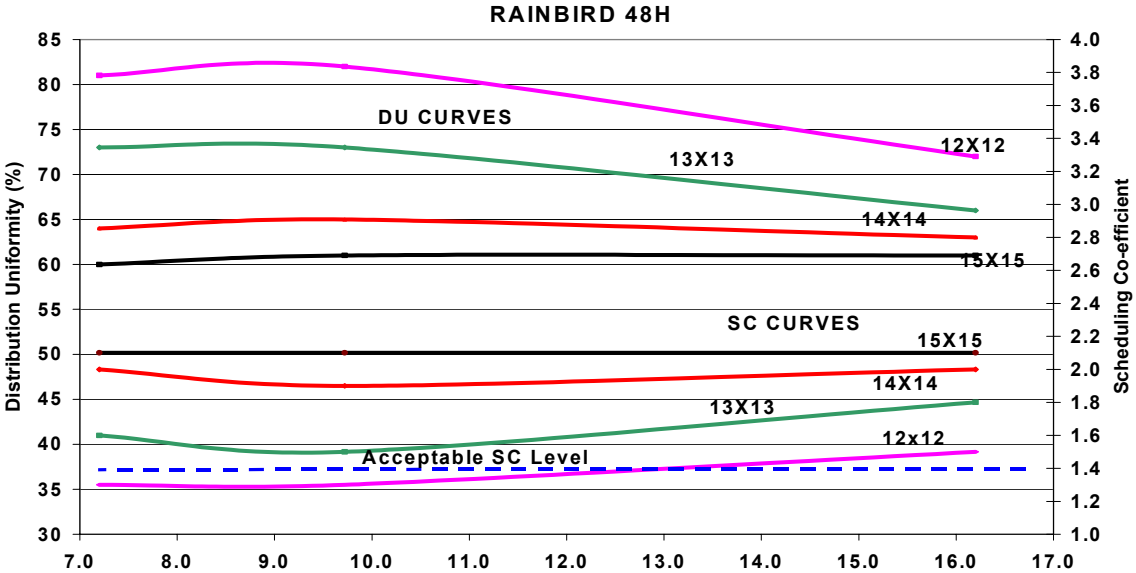


Figure 2.63. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The Rainbird 48H with a 5.2 mm single nozzle at spacings of 9 m x12 m, 9 m x14 m and 9 m x 15 m had DU's well above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.64 and Figure 2.65). At all other spacings the DU fell below 75 per cent and the SC increased above 1.4 as wind speed increased above 8 to 9 km/hr.

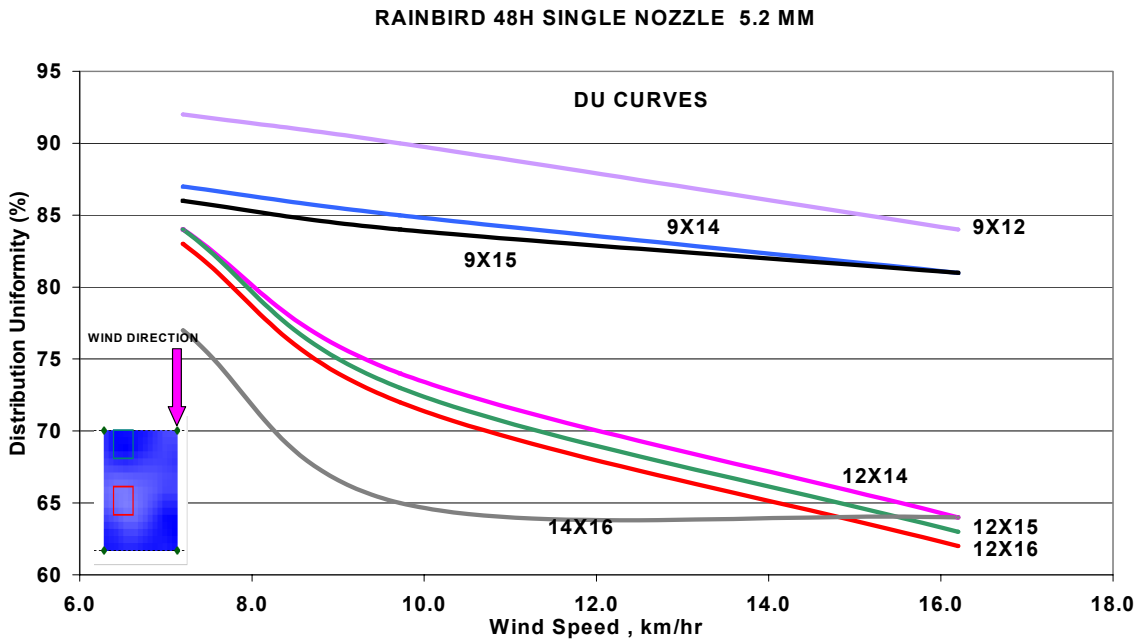


Figure 2.64. Effect of wind speed on distribution uniformity in rectangular configuration.

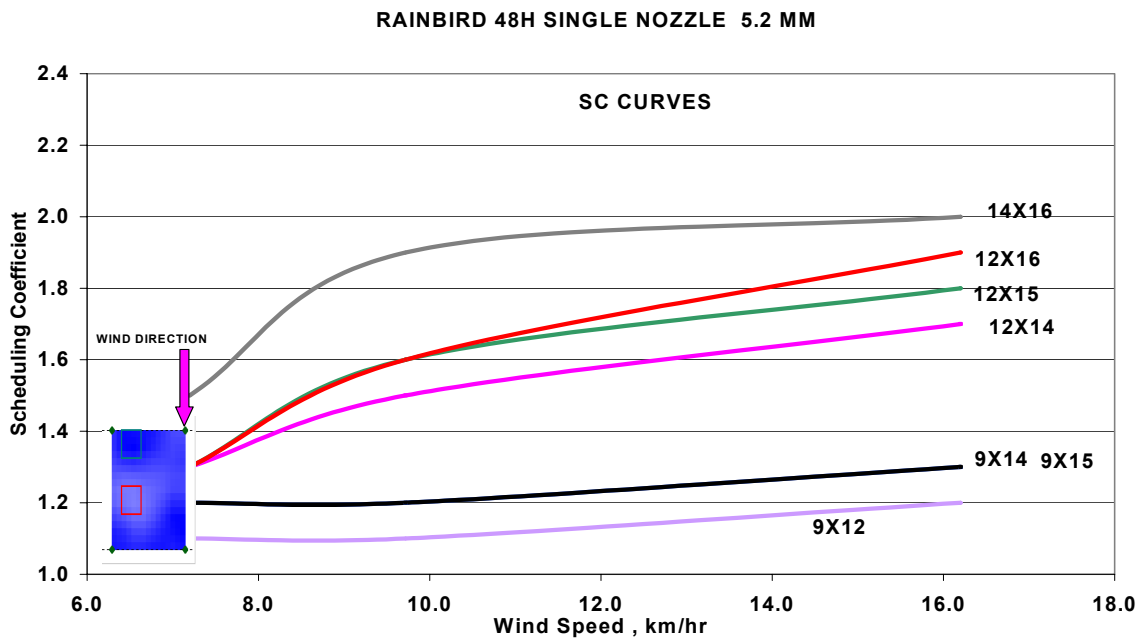


Figure 2.65. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: Possibly 12 m x 12 m.
Rectangular configuration: 9 x 12 m, 9 m x 14 m and 9 m x 15 m.

4.3.6 TORO™

Model: **Pope Premier**
Jet size(s): No. 10
Test pressure: 300 kPa
Flow rate: 18.0 litres/minute
Diameter of throw: 27.1 metres

Results

Five tests were conducted on the Pope Premier single nozzle sprinkler at an operating pressure of 300 kPa for average wind speeds between 5.4 and 16.2 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.18.

Table 2.18 Prevailing wind speed and wind direction during testing of Pope Premier single nozzle No. 10

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
68	5.4	17.3	0.0	0.9	164	71
111	8.6	18.7	0.0	1.2	160	48
112	11.9	23.0	3.6	1.2	65	20
69	12.2	25.2	4.0	1.2	113	26
90	16.2	36.7	4.0	1.8	86	19

Square configuration

The Pope Premier with a single nozzle No. 10 when spaced at 10 m x 10 m, 12 m x 12 m and 13 m x 13 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) over the range of wind speeds tested (Figure 2.66). At a 14 m x 14 m spacing the DU fell below 75 per cent and the SC increased above 1.4 (maximum acceptable level) as wind speeds increased.

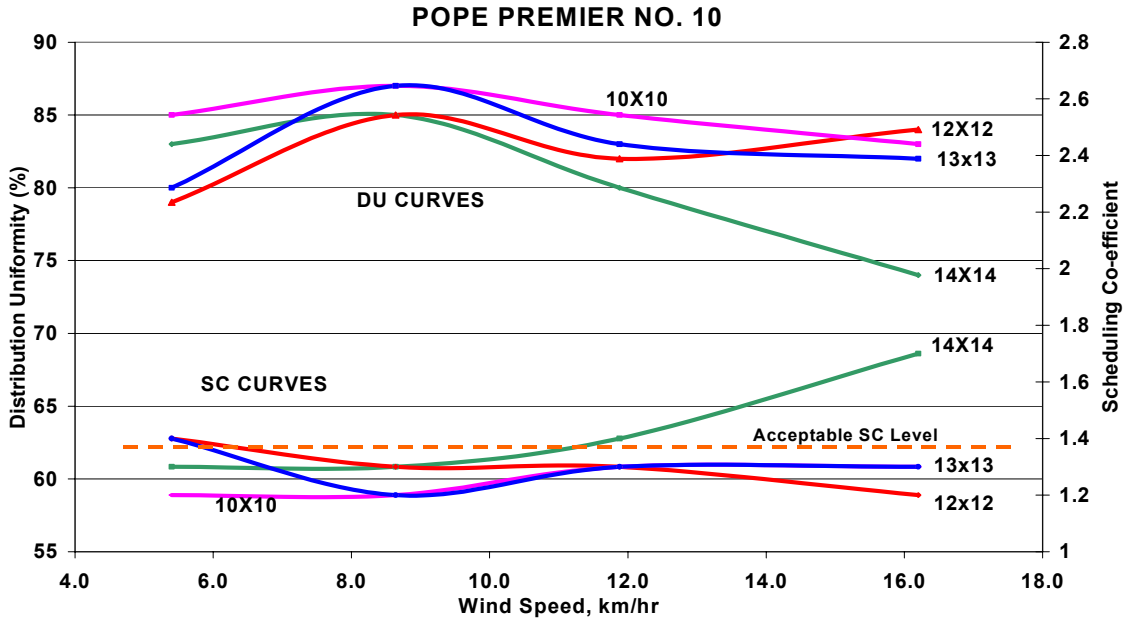


Figure 2.66. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The Pope Premier single nozzle at spacings of 9 m x 12 m and 9 m x 14 m had DU's above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.67 and Figure 2.68). At all other spacings the DU fell below 75 per cent and the SC increased above 1.4 as wind speed increased.

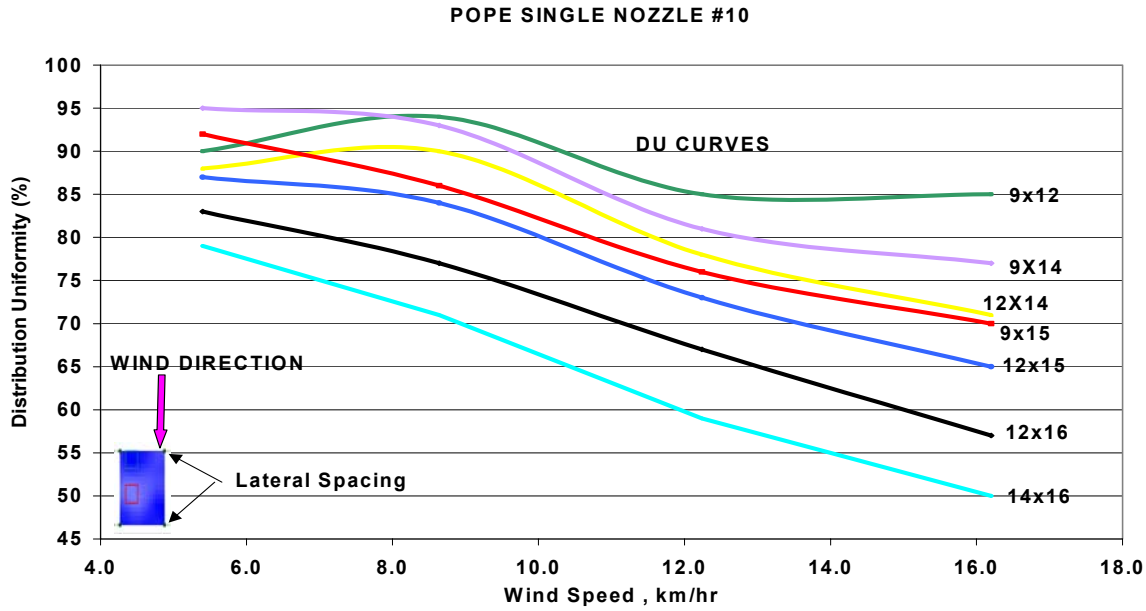


Figure 2.67. Effect of wind speed on distribution uniformity in rectangular configuration.

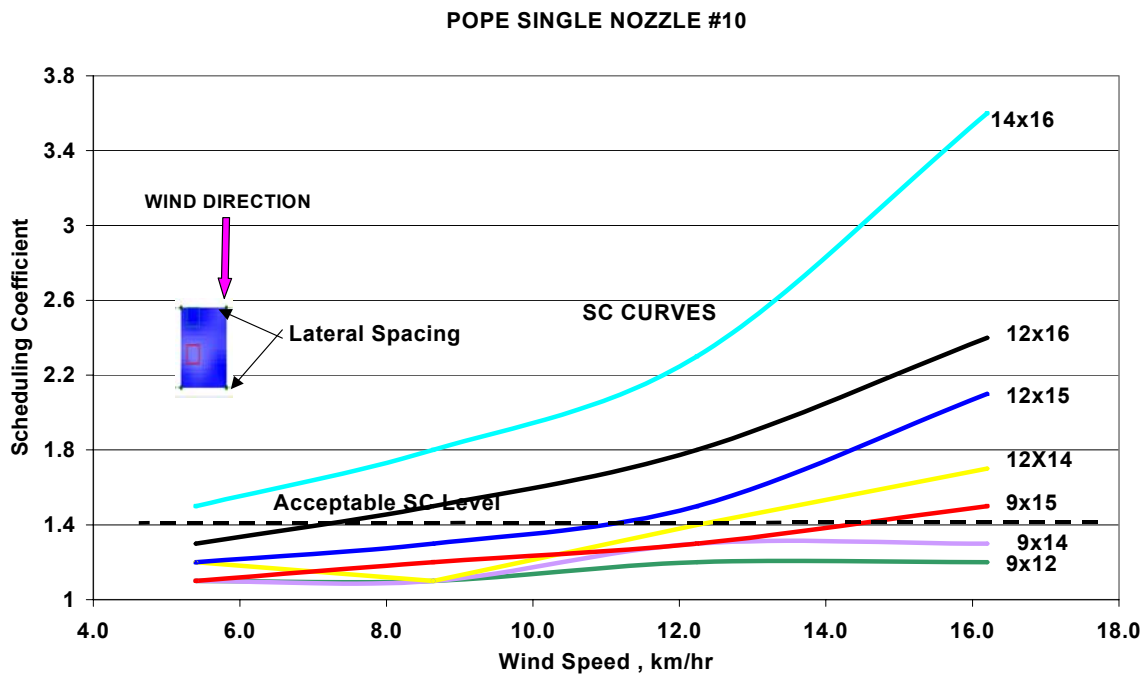


Figure 2.68. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 10 m x 10 m, 12 m x 12 m and 13 m x 13 m.
Rectangular configuration: 9 m x 12 m and 9 m x 14 m.

Model: **Pope Premier**
Jet size(s): No. 10 x 6
Test pressure: 300 kPa
Flow rate: 22.5 litres/minute
Diameter of throw: 27.1 metres

Results

Five tests were conducted on the Pope Premier double nozzle sprinkler at an operating pressure of 300 kPa for average wind speeds between 2.3 and 18.7 km/hr. The wind speed data measured during each test on this sprinkler is shown in Table 2.19.

Table 2.19 Prevailing wind speed and wind direction during testing of Pope Premier double nozzle No. 10 x 6

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
25	2.3	7.2	0	0.4	174	97
53	5.8	18	0	1.0	173	70
130	9.4	22.3	0.4	1.2	205	41
185	11.2	18.7	2.5	0.9	80	32
200	18.7	30.6	7.2	1.4	204	13

Square configuration

The Pope Premier with a double nozzle No. 10 x 6 when spaced at 10 m x 10 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) over the range of wind speeds tested (Figure 2.69). At a 12 m x 12 m spacing the DU fell below 75 per cent and the SC increased above 1.4 (maximum acceptable level) as wind speeds increased above 10 km/hour. The sprinkler performed poorly at spacings of 13 m x 13 m and 14 m x 14 m.

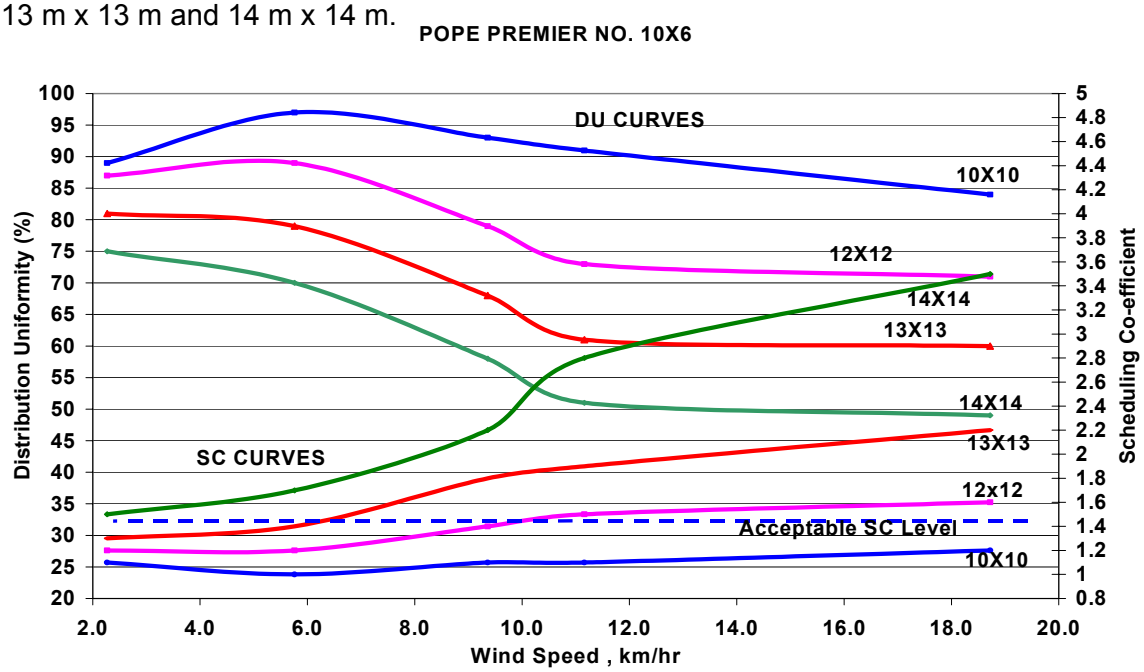


Figure 2.69. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The Pope Premier with a double nozzle No. 10 x 6 at spacings of 9 m x12 m had a DU above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.70 and Figure 2.71). At a 9 m x14 m spacing the DU fell below 75 per cent and the SC increased above 1.4 as wind speed increased above 7 km/hour. The uniformity of all other rectangular spacings tested was poor.

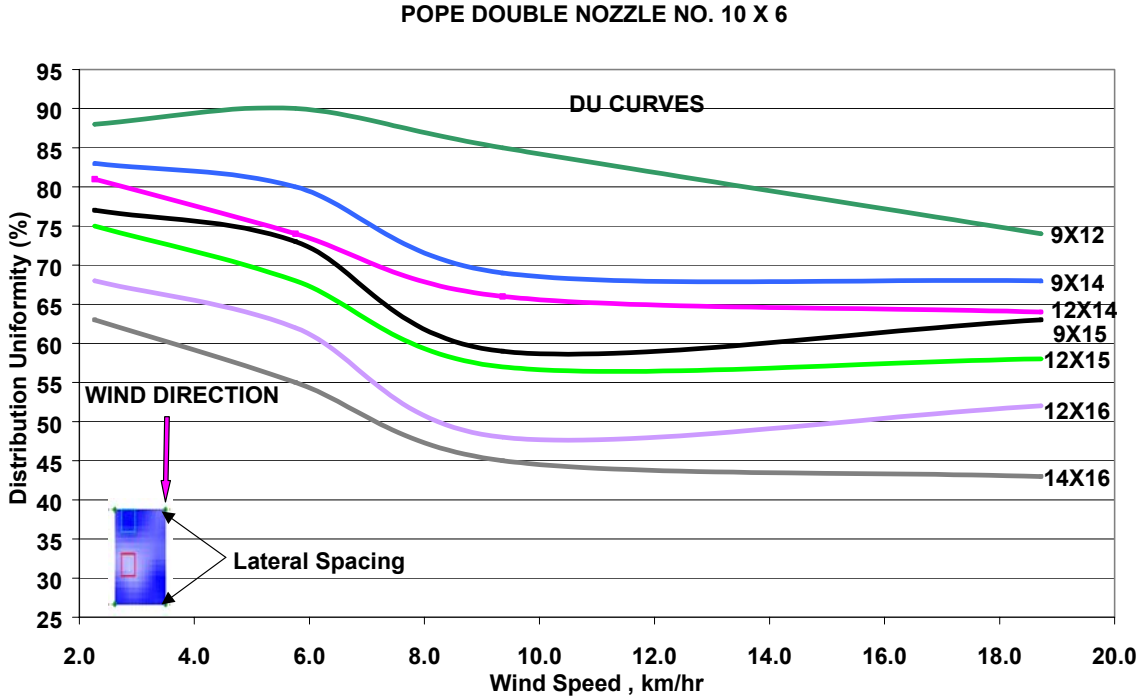


Figure 2.70. Effect of wind speed on distribution uniformity in rectangular configuration.

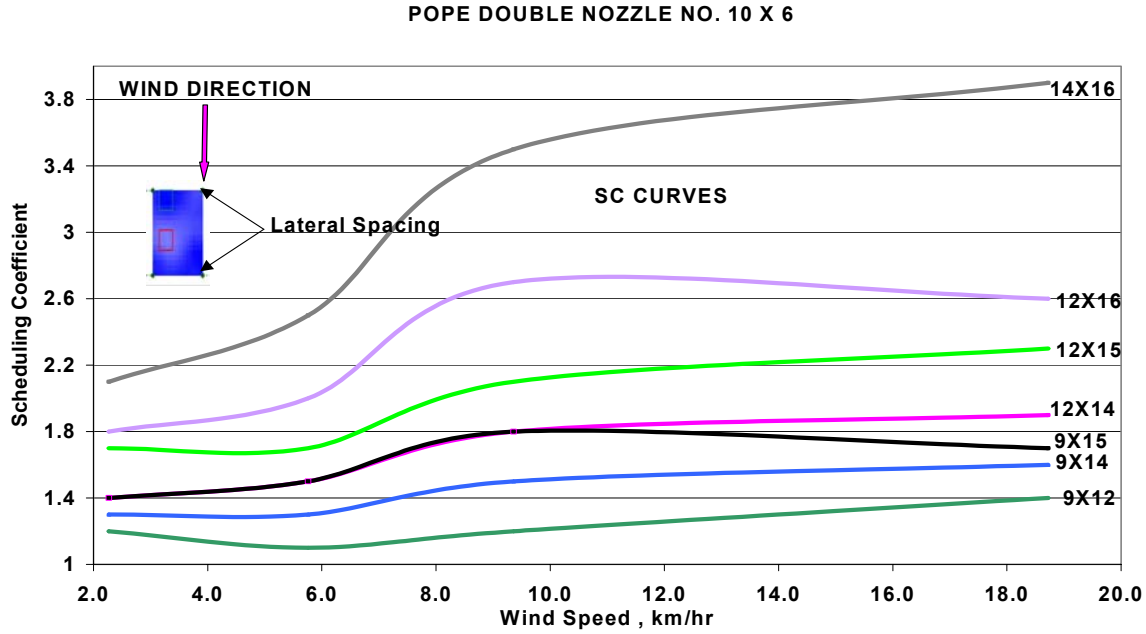


Figure 2.71. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 10 m x 10 m.
Rectangular configuration: 9 m x 12 m.

Model: **Pope Premier**
Jet size(s): No. 12
Test pressure: 300 kPa
Flow rate: 24.2 litres/minute
Diameter of throw: 29.8 metres

Results

Four tests were conducted on the Pope Premier single nozzle sprinkler at an operating pressure of 300 kPa for average wind speeds between 4.7 and 19.4 km/hour. The wind speed data measured during each test on this sprinkler is shown in Table 2.20.

Table 2.20 Prevailing wind speed and wind direction during testing of Pope Premier single nozzle No. 12

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
75	4.7	12.6	0	0.6	43	46
113	9.0	19.8	0	1.0	62	33
72	13.7	26.3	5.0	1.3	79	16
91	19.4	33.8	8.6	1.4	99	13

Square configuration

The Pope Premier single nozzle No. 12 when spaced at 10 m x 10 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) over the range of wind speeds tested (Figure 2.72). At a 12 m x 12 m spacing the uniformity was marginal as wind speeds increased above about 10 km/hour.

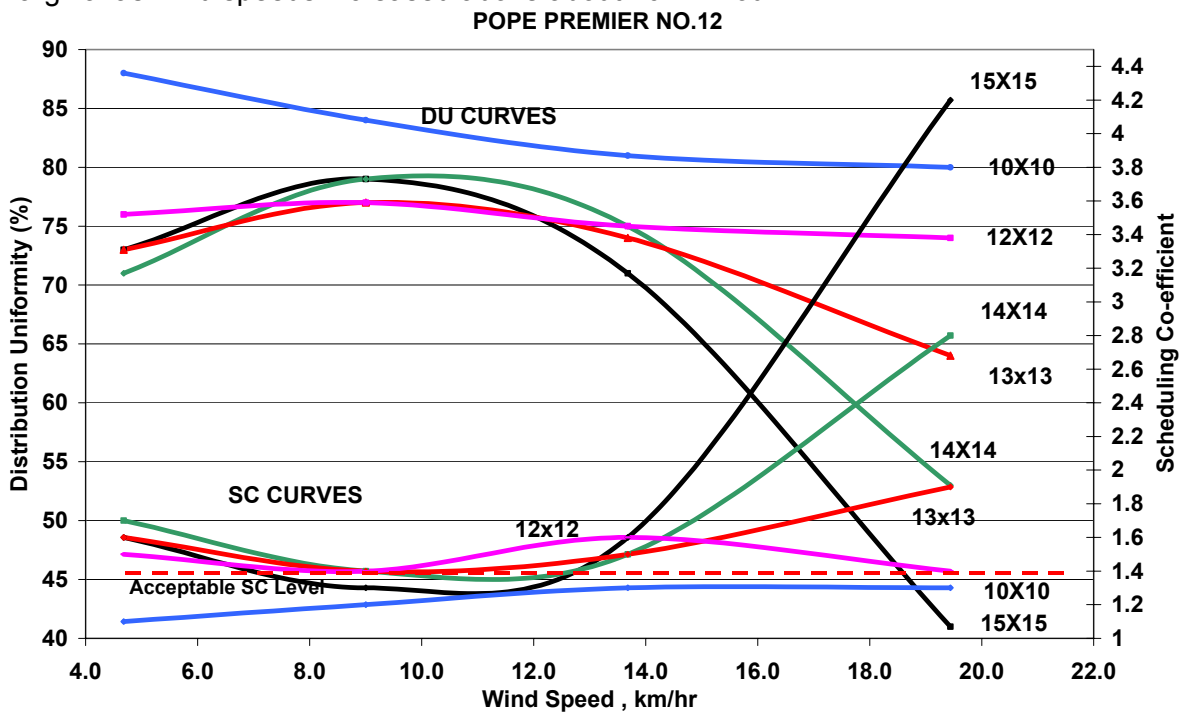


Figure 2.72. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

The Pope Premier single nozzle at spacings of 9 m x12 m and 9 m x14 m had DU's above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.73 and Figure 2.74). At a spacing of 12 m x 14 m this sprinkler had an acceptable uniformity for wind speeds below 18 km/hour. At all other spacings the DU fell below 75 per cent and the SC increased above 1.4 as wind speed increased.

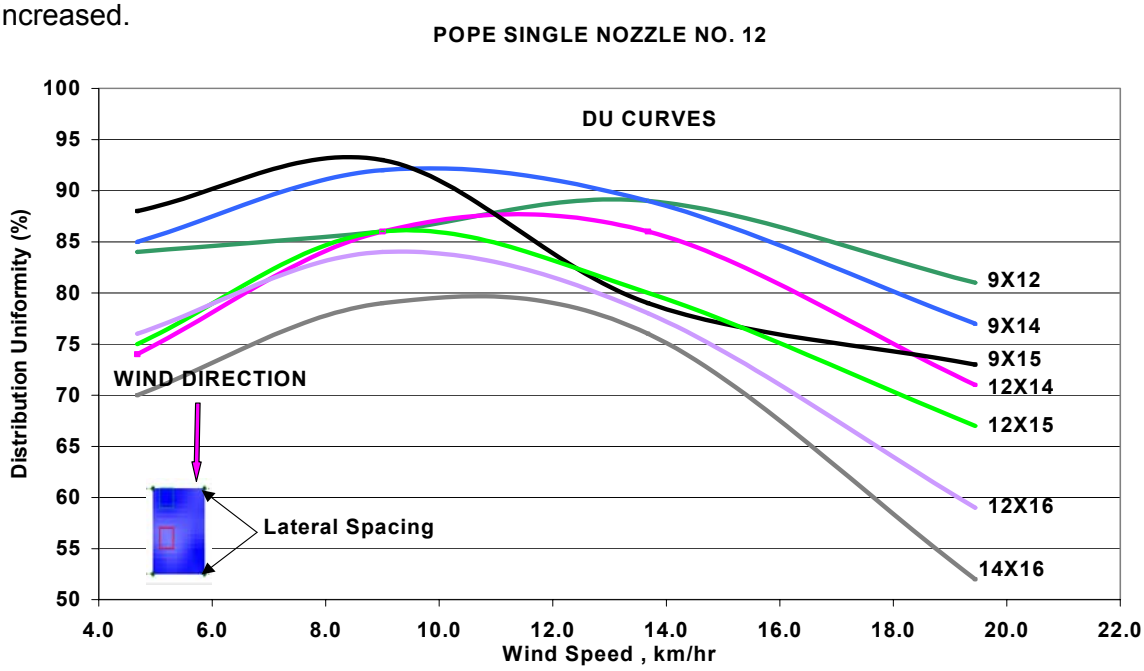


Figure 2.73. Effect of wind speed on distribution uniformity in rectangular configuration.

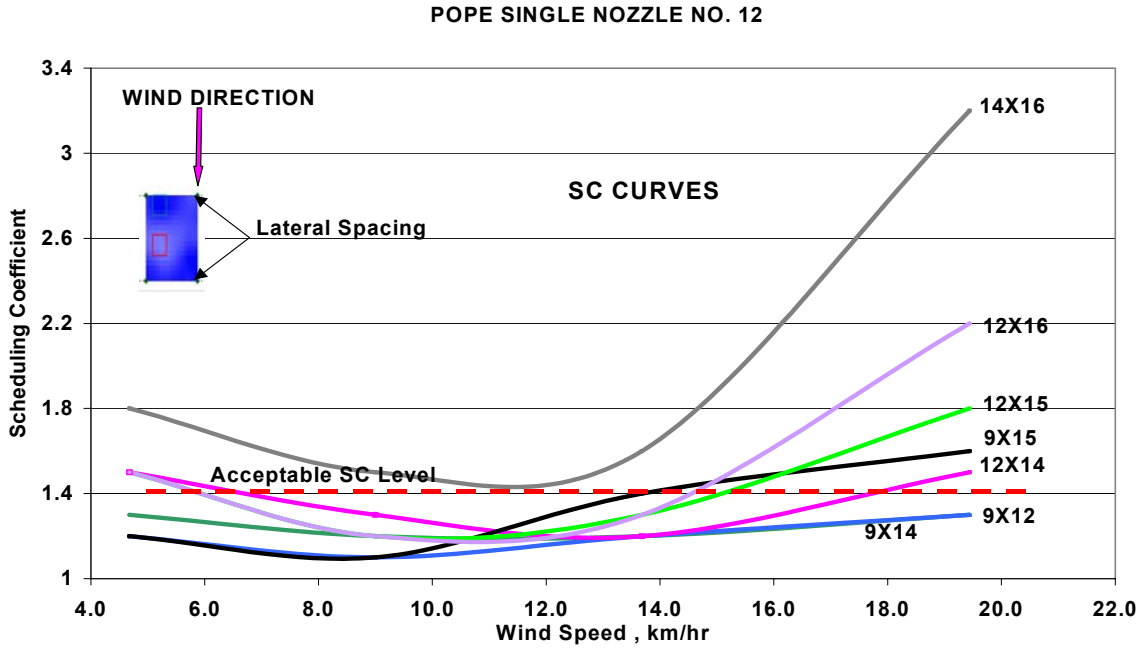


Figure 2.74. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 10 m x 10 m and possibly 12 m x 12 m.
Rectangular configuration: 9 m x 12 m and 9 m x 14 m.

Model: **Pope Premier**
Jet size(s): No. 12 x 6
Test pressure: 300 kPa
Flow rate: 30.8 litres/minute
Diameter of throw: 29.8 metres

Results

Five tests were conducted on the Pope Premier double nozzle sprinkler with size 12 x 6 jets at an operating pressure of 300 kPa for average wind speeds between 4.3 and 21.6 km/hour. The wind speed data measured during each test on this sprinkler is shown in Table 2.21.

Table 2.21 Prevailing wind speed and wind direction during testing of Pope Premier double nozzle No. 12 x 6

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
76	4.3	11.5	0	0.7	185	100
120	9.0	18.7	2.2	0.9	224	20
77	11.2	22.7	2.9	1.0	130	21
73	14.0	29.2	4.7	1.5	91	21
170	21.6	43.2	6.5	2.1	94	13

Square configuration

The Pope Premier with double nozzles No. 12 x 6 when spaced at 12 m x 12 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) over the range of wind speeds tested (Figure 2.75). At a 13 m x 13 m spacing the uniformity was marginal as across the range of wind speeds tested. When spaced at 14 m x 14m this sprinkler had an unacceptable uniformity when wind speed increased above 8 km/hour.

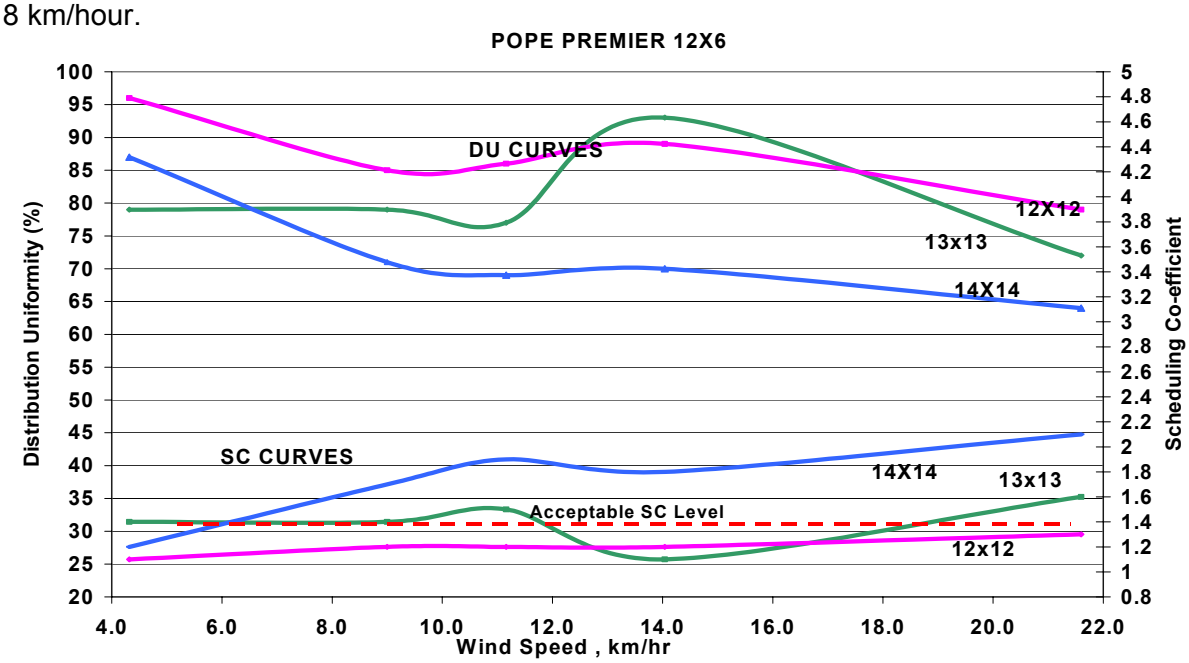


Figure 2.75. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

When spaced at 9 m x 12 m and 9 m x 14 m this sprinkler had DU's above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 4.76 and Figure 4.77). At a spacing of 12 m x 14 m this sprinkler had an acceptable uniformity (SC < 1.4) for wind speeds below 17 km/hour. At all other spacings the DU fell below 75 per cent and the SC increased above 1.4 as wind speed increased.

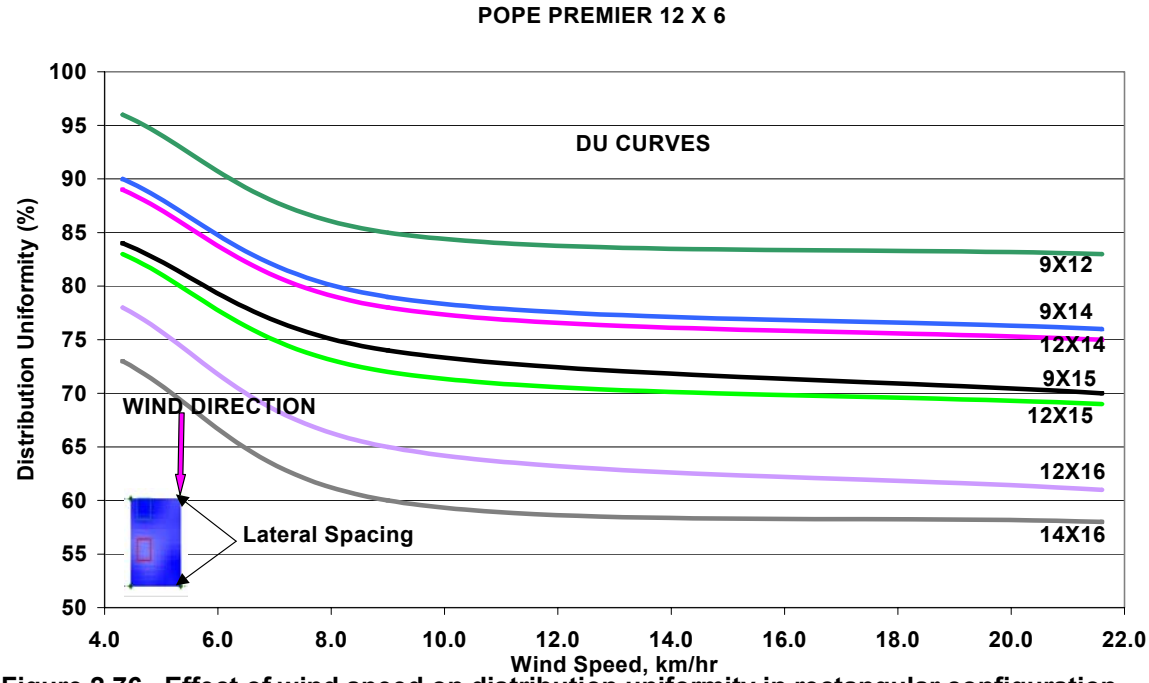


Figure 2.76. Effect of wind speed on distribution uniformity in rectangular configuration.

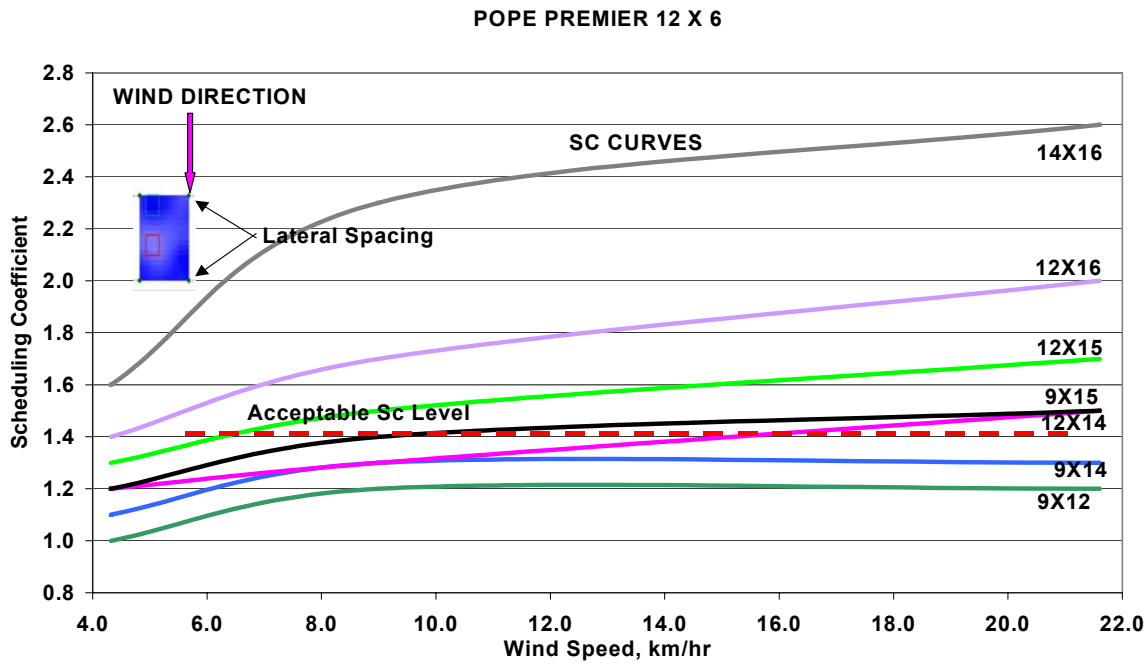


Figure 2.77. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m and possibly 13 m x 13 m.
Rectangular configuration: 9 m x 12 m and 9 m x 14 m.

Model: **Rainspray Model 2**
Jet size(s): No. 12
Test pressure: 400 kPa
Flow rate: 29 litres/minute
Diameter of throw: 31 metres

Results

Five tests were conducted on the Rainspray Model 2 sprinkler with a size 12 jet at an operating pressure of 400 kPa for average wind speeds between 7.2 and 20.5 km/hour. The wind speed data measured during each test on this sprinkler is shown in Table 2.22.

Table 2.22 Prevailing wind speed and wind direction during testing of Rainspray Model 2 single nozzle No. 12

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
189	7.2	14.8	1.4	0.8	90	32
79	8.3	21.6	0	1.2	143	60
169	14.4	30.0	2.5	1.5	111	22
174	17.6	35.3	7.2	1.5	89	15
92	20.5	34.9	7.9	1.7	102	14

Square configuration

The Rainspray Model 2 with a single nozzle No.12 when spaced at 12 m x 12 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) for wind speeds below 19 km /hour (Figure 2.78). When spaced at 13 m x 13 m this sprinkler had an unacceptable uniformity when wind speed increased above 18 km/hour. When spaced at 14 m x 14 m and 15 m x 15 m the SC was greater then 1.4 over the range of wind speeds tested.

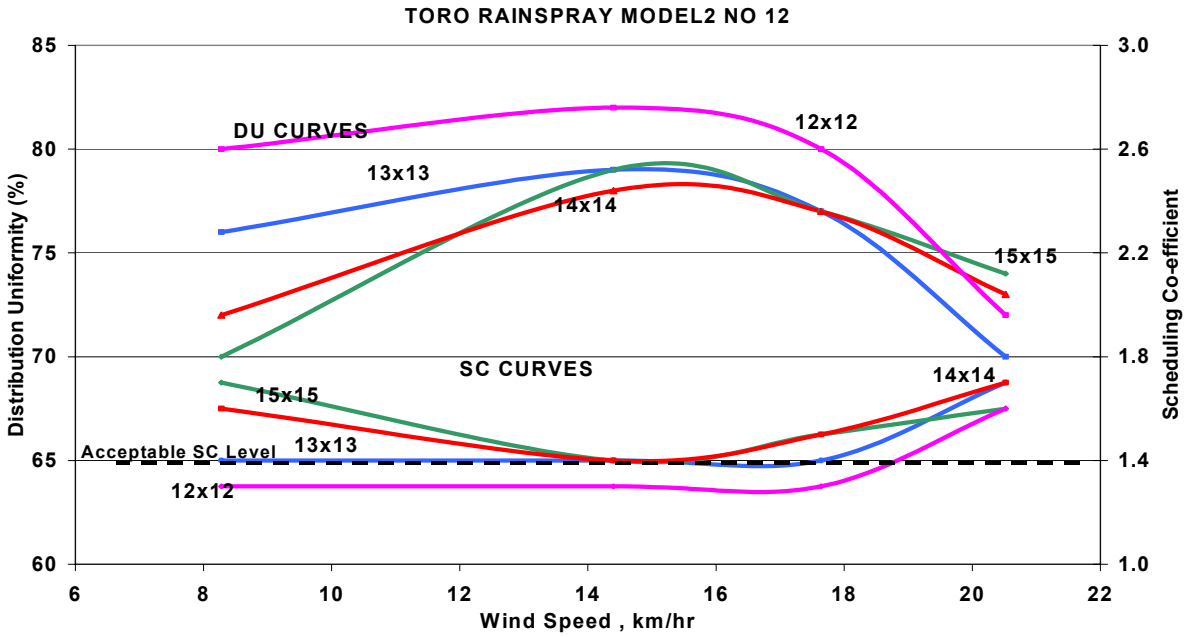


Figure 2.78. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

When spaced at 9 m x 14 m this sprinkler had DU's above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.79 and Figure 2.80). At a spacing of 9 m x 15 m this sprinkler had an acceptable uniformity (SC < 1.4) for wind speeds below 19 km/hour. At a spacing of 12 m x 14 m this sprinkler had an acceptable uniformity (SC < 1.4) for wind speeds below 14 km/hour. At all other spacings the DU fell below 75 per cent and the SC increased above 1.4 as wind speed increased.

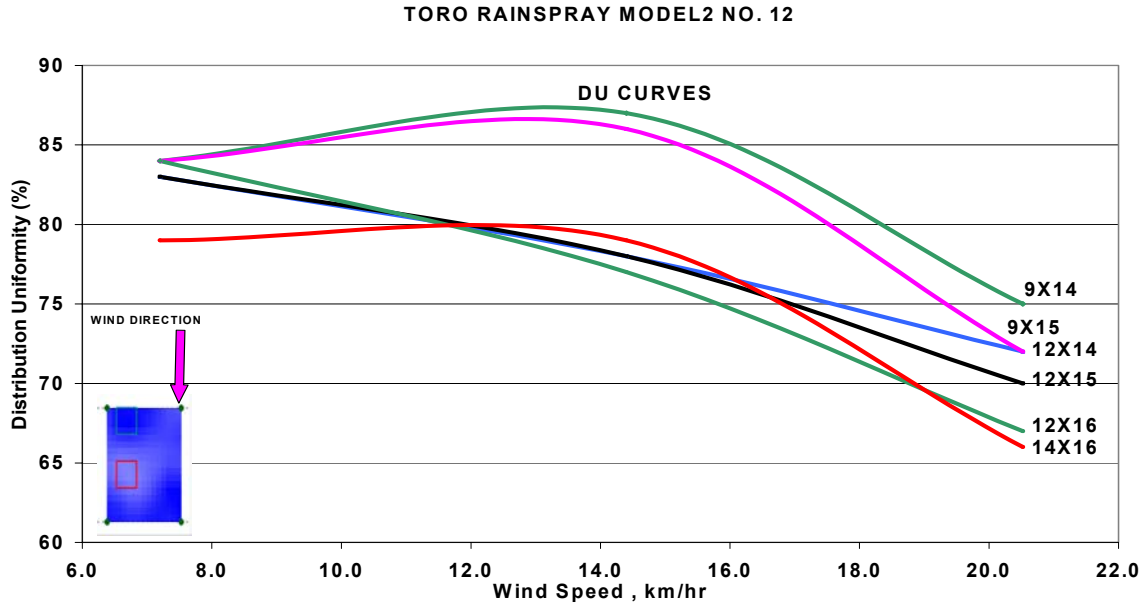


Figure 2.79. Effect of wind speed on distribution uniformity in rectangular configuration.

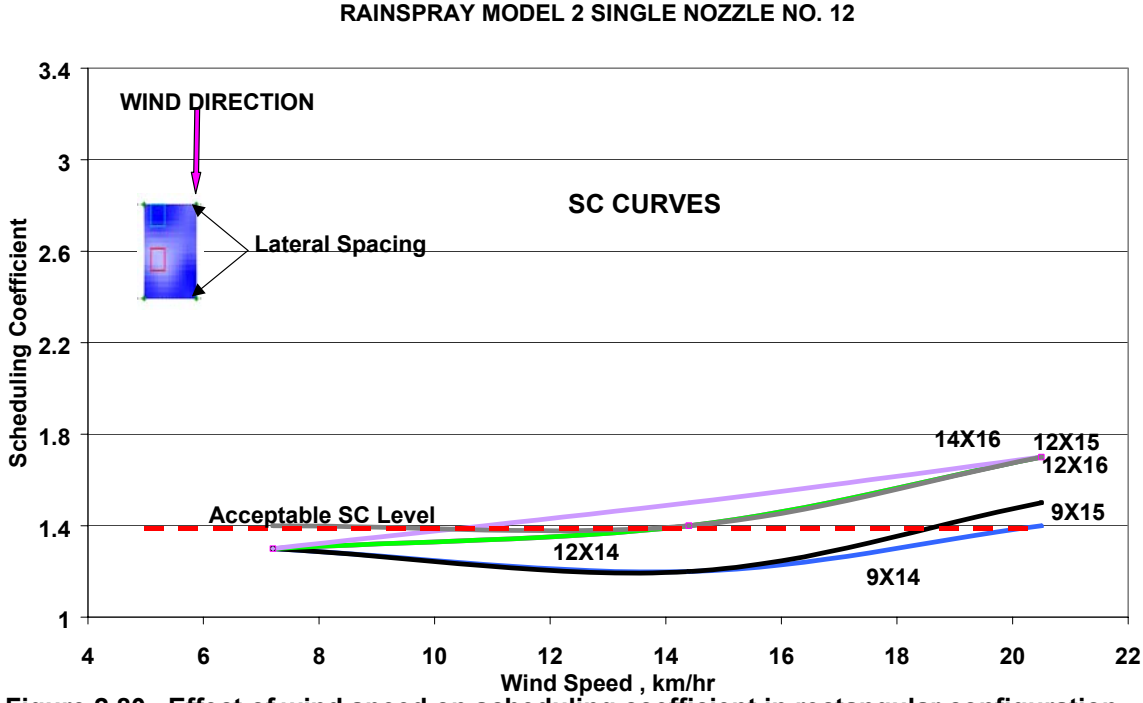


Figure 2.80. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m and possibly 13 m x 13 m.
Rectangular configuration: 9 m x 14 m and possibly 9 m x 15 m.

Model: **Rainspray Model 2**
Jet size(s): No. 12 x 8
Test pressure: 400 kPa
Flow rate: 43 litres/minute
Diameter of throw: 31 metres

Results

Five tests were conducted on the Rainspray Model 2 sprinkler with a size 12 x 8 jet at an operating pressure of 400 kPa for average wind speeds between 7.9 and 15.4 km/hour. The wind speed data measured during each test on this sprinkler is shown in Table 2.23.

Table 2.23 Prevailing wind speed and wind direction during testing of Rainspray Model 2 single nozzle No. 12

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
188	7.9	15.4	2.9	0.7	85	20
127	9.0	18.0	2.5	0.9	251	28
78	9.4	19.1	2.2	1.1	115	24
124	14.0	22.7	2.9	1.1	211	14
168	15.4	30.6	5.0	1.5	99	28

Square configuration

The Rainspray Model 2 with a double nozzle No.12 x 8 when spaced at 12 m x 12 m and 14 m x 14 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) over the range of wind speeds tested (Figure 2.81). When spaced at 15 m x 15 m this sprinkler had an unacceptable SC when wind speed increased above 9 km/hour. When spaced at 16 m x 16 m the uniformity was unacceptable over the range of wind speeds tested.

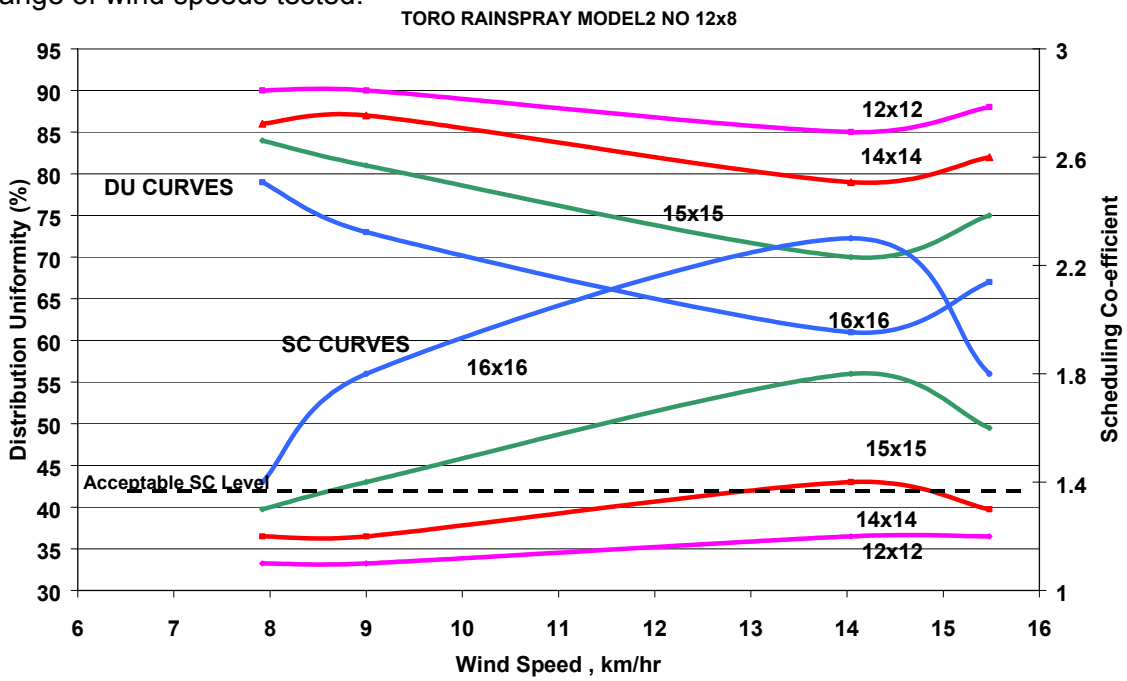


Figure 2.81. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

When spaced at 9 m x 14 m, 12 m x 14 m, 9 m x 15 m and 12 m x 15 m this sprinkler had DU's above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.82 and Figure 2.83). At all other spacings the DU fell below 75 per cent and the SC increased above 1.4 over the range of wind speeds tested.

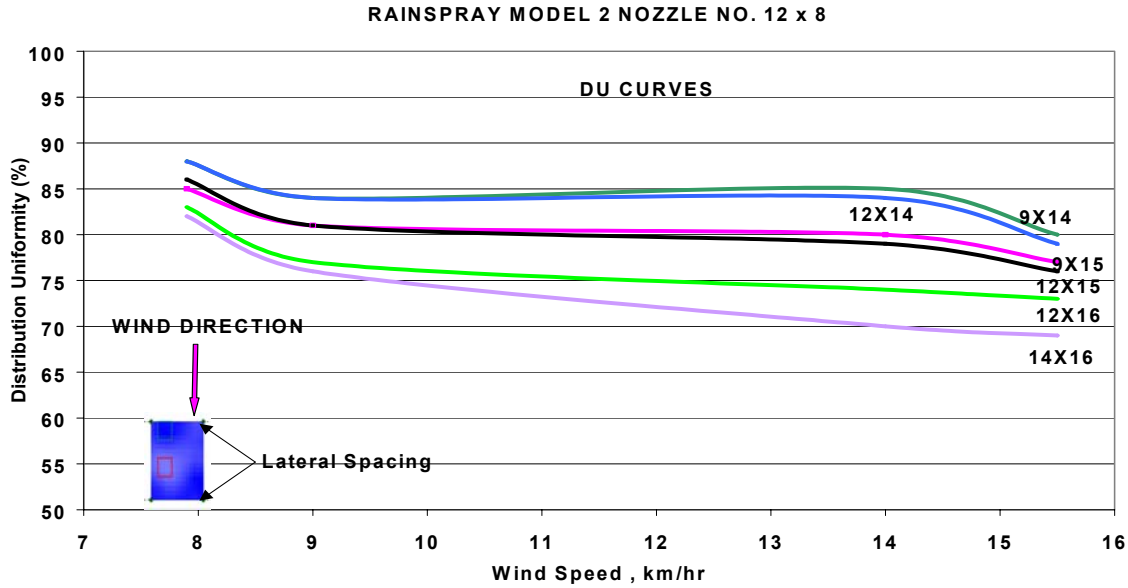


Figure 2.82 Effect of wind speed on distribution uniformity in rectangular configuration.

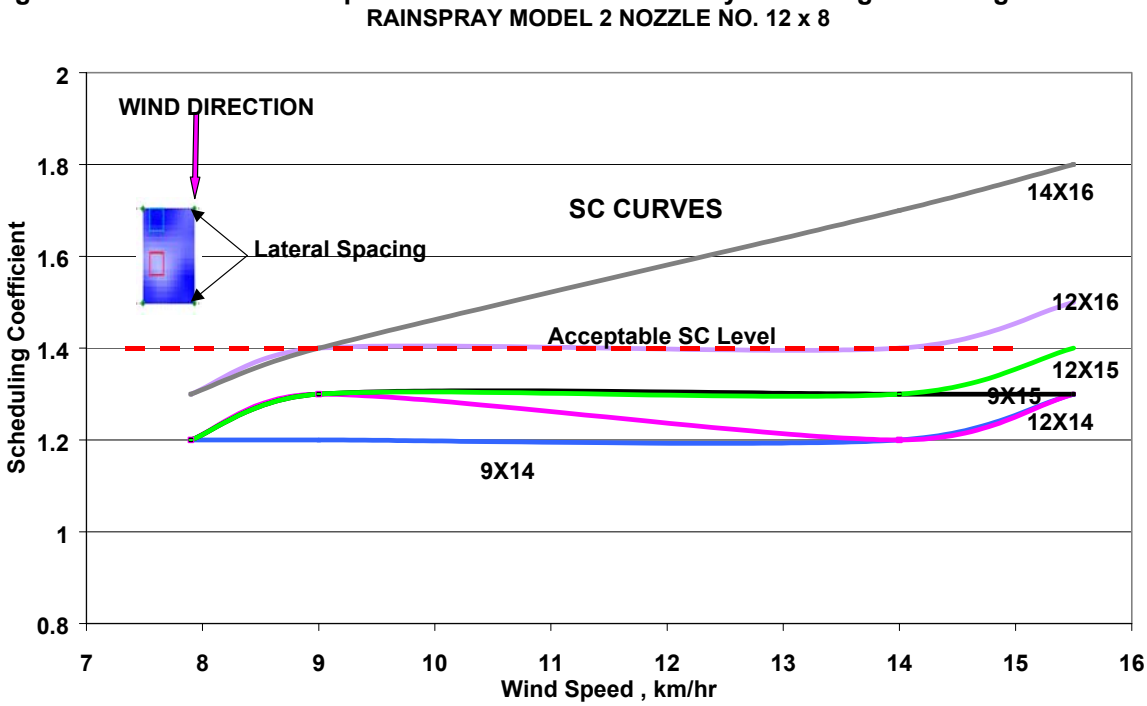


Figure 2.83 Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m and 14 m x 14 m.
Rectangular configuration: 9 m x 14 m, 12 m x 14 m, 9 m x 15 m and 12 m x 15 m.

Model: **Rainspray Model 2**
Jet size(s): No. 14
Test pressure: 400 kPa
Flow rate: 52 litres/minute
Diameter of throw: 33 metres

Results

Seven tests were conducted on the Rainspray Model 2 sprinkler with a size 14 jet at an operating pressure of 400 kPa for average wind speeds between 4.6 and 19.1 km/hour. The wind speed data measured during each test on this sprinkler is shown in Table 2.24.

Table 2.24 Prevailing wind speed and wind direction during testing of Rainspray Model 2 single nozzle No. 14

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
31	4.6	11.2	0	0.7	88	15
80	5.8	15.1	1.1	0.8	51	28
191	8.3	17.6	3.6	0.7	37	17
34	11.5	21.6	3.6	1.1	247	19
30	13.3	28	2.2	1.3	85	27
167	15.1	28.8	6.1	1.3	103	24
175	19.1	30.6	6.5	1.6	95	15

Square configuration

The Rainspray Model 2 single nozzle No. 14 when spaced at 12 m x 12 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.84). When spaced at 13 m x 13 m this sprinkler had an unacceptable uniformity when wind speed increased above 12 km/hour. When spaced at 14 m x 14 m and 15 m x 15 m the SC was greater then 1.4 when the wind speed increased above 7 km/hour.

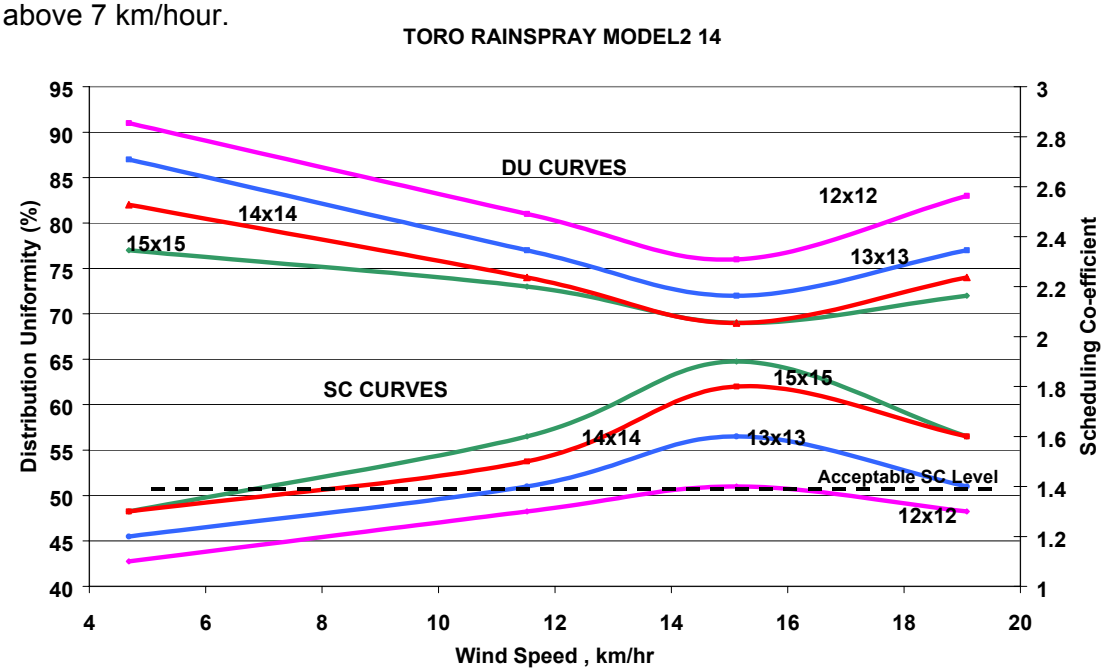


Figure 2.84. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

When spaced at 9 m x 14 m and 9 m x 15 m this sprinkler had DU's above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.85 and Figure 2.86). At a spacing of 12 m x 14 m this sprinkler had an acceptable uniformity (SC < 1.4) for wind speeds below 11 km/hour. At all other spacings the SC increased above 1.4 as wind speed increased.

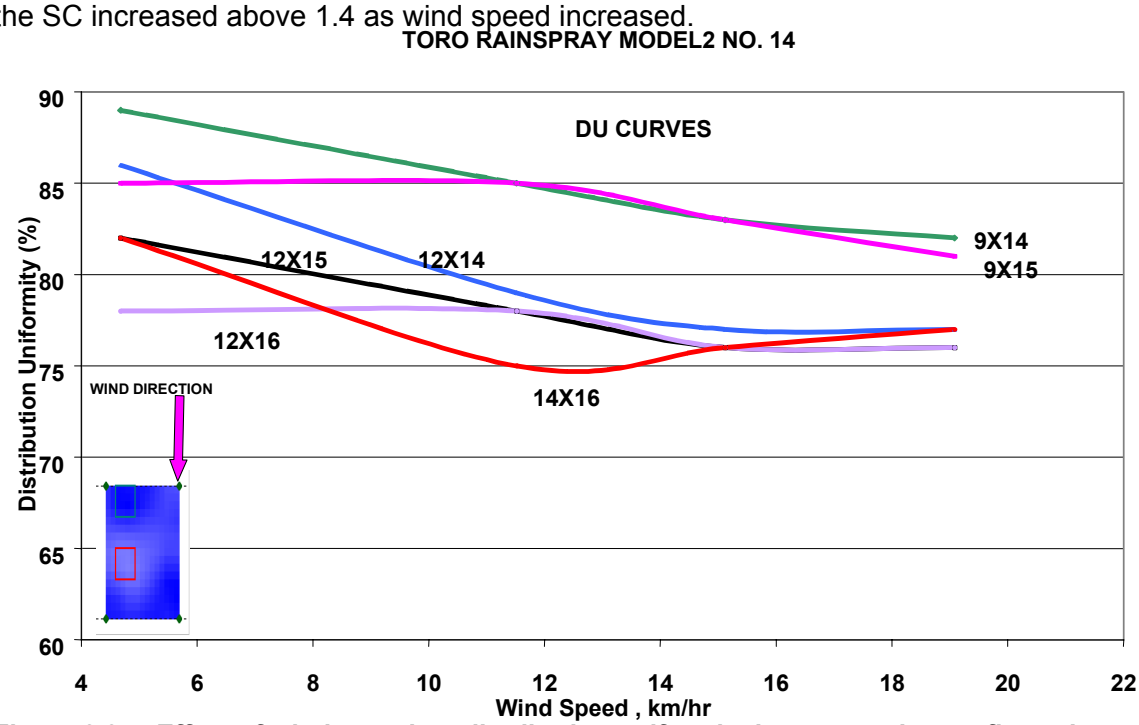


Figure 2.85. Effect of wind speed on distribution uniformity in rectangular configuration.

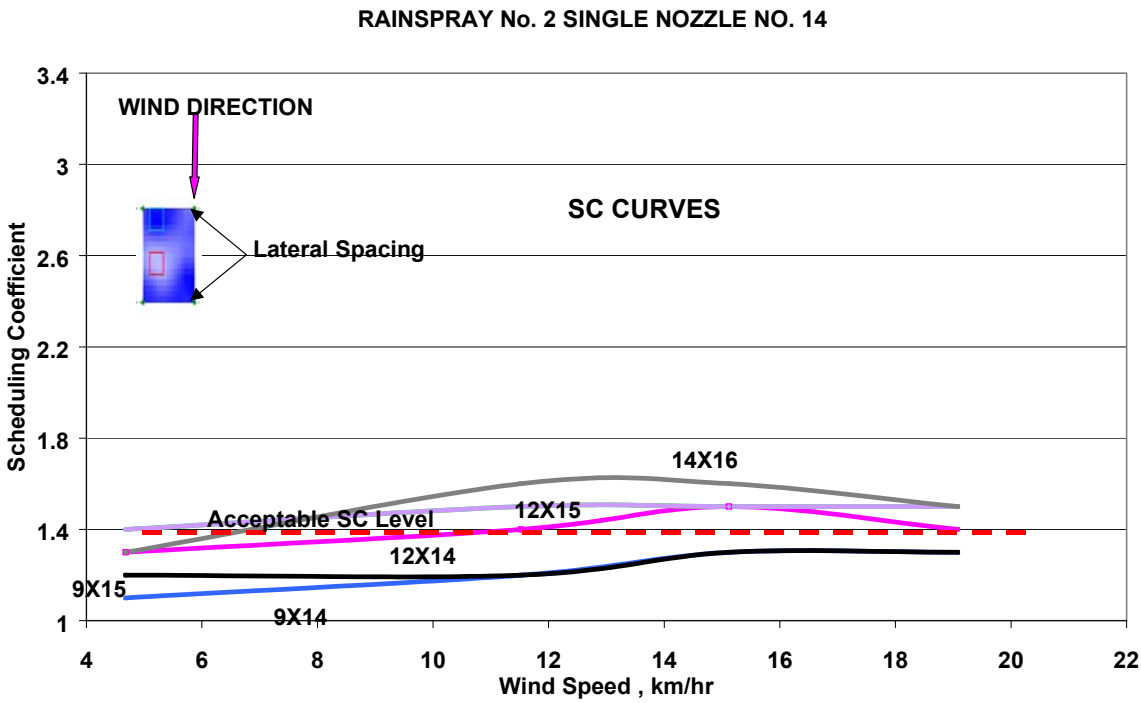


Figure 2.86. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m.
Rectangular configuration: 9 m x 14 m and 9 m x 15 m.

Model: **Rainspray Model 2**
Jet size(s): No. 14 x 8
Test pressure: 400 kPa
Flow rate: 54 litres/minute
Diameter of throw: 33 metres

Results

Six tests were conducted on the Rainspray Model 2 sprinkler with size 14 x 8 jets at an operating pressure of 400 kPa for average wind speeds between 5.3 and 16.9 km/hour. The wind speed data measured during each test on this sprinkler is shown in Table 2.25.

Table 2.25. Prevailing wind speed and wind direction during testing of Rainspray Model 2 single nozzle No. 14 x 8

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
32	5.3	11.5	1.1	0.5	275	54
81	7.2	13.7	0	0.9	130	90
33	11.8	21.6	5.4	0.9	241	21
155	11.9	23.0	2.5	1.1	218	29
176	15.8	38.9	15.8	1.7	92	22
166	16.9	27.7	9.7	1.1	99	15

Square configuration

The Rainspray Model 2 with double nozzles No.14 x 8 when spaced at 12 m x 12 m, 14 m x 14 m and 15 m x 15 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) for the wind speeds tested (Figure 2.87). When spaced at 16 m x 16 m this sprinkler had an unacceptable uniformity when wind speed increased above 14 km/hour.

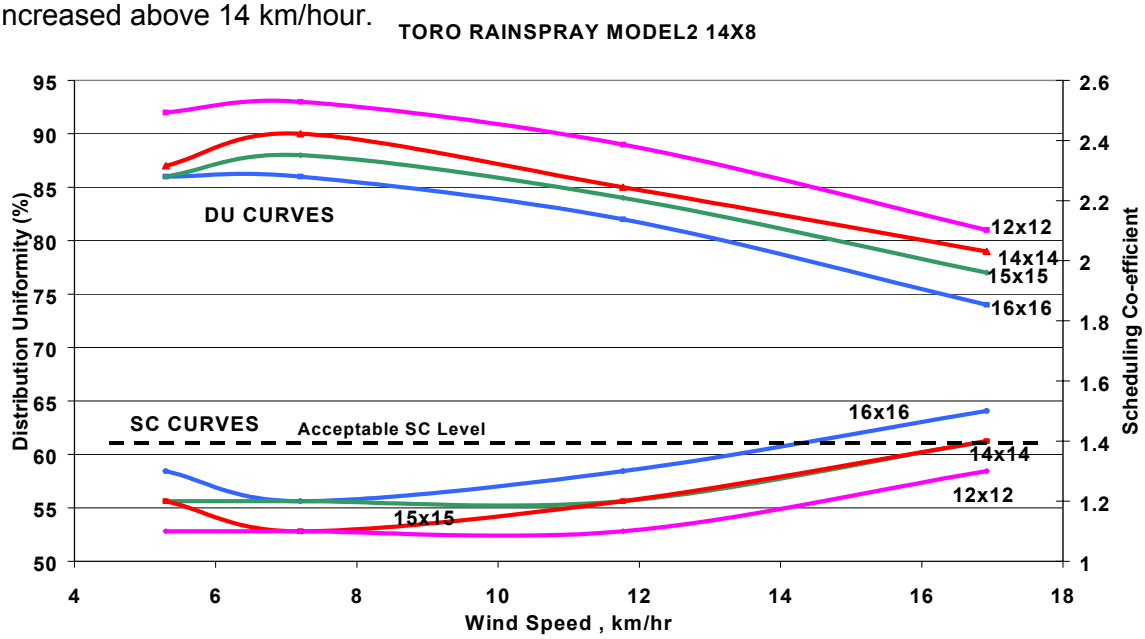


Figure 2.87. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

This sprinkler had DU's above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) at all spaciungs over the range of wind speeds tested (Figure 2.88 and Figure 2.89). Unfortunately uniformity data was available for wind speeds to a maximum of 16.9 km/hour. Figure 4.91 shows that at spacings of 12 m x 16 m, 12 m x 15 m and 14 m x 16 m the SC graph increases to 1.4 at a wind speed of 17 km/hour.

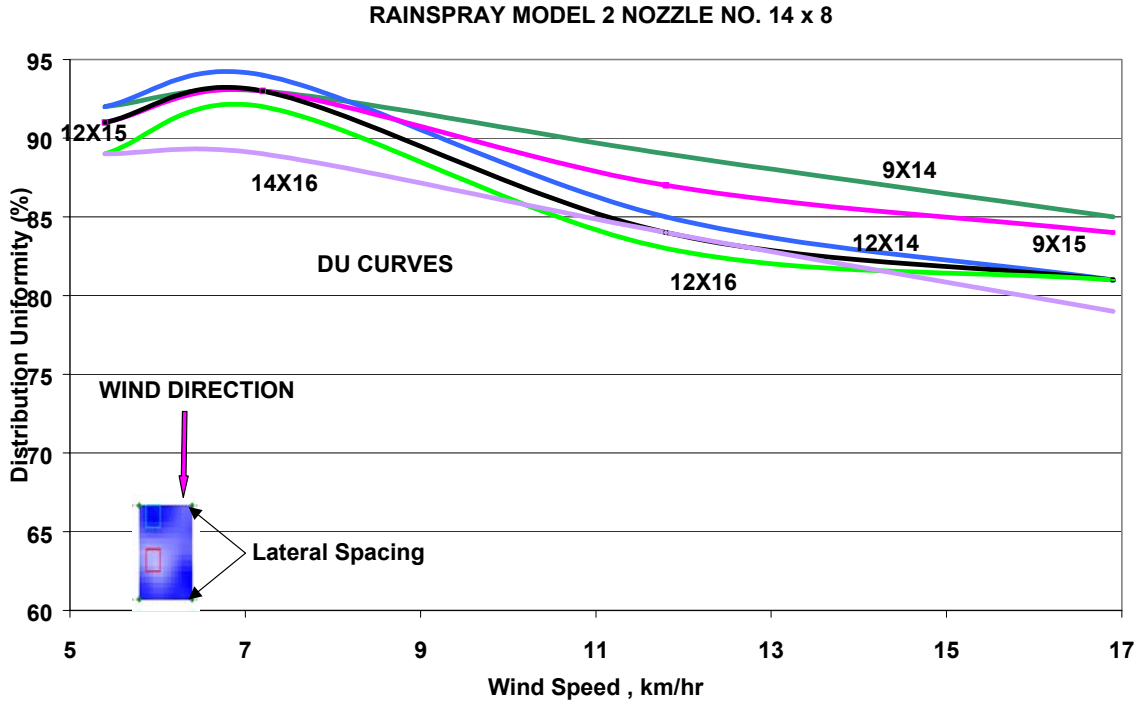


Figure 2.88. Effect of wind speed on distribution uniformity in rectangular configuration.

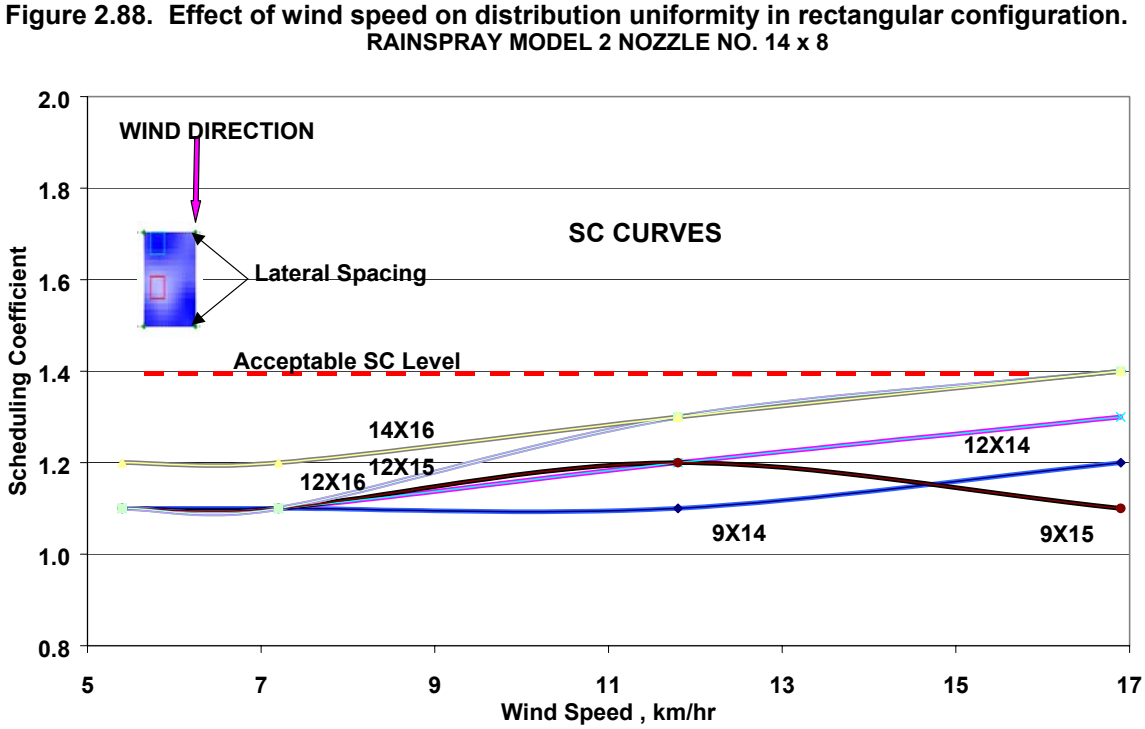


Figure 2.89. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m, 14 m x 14m and 15 m x 15 m.

Rectangular configuration: 9 m x 14 m, 9 m x 15 m, 12 m x 14 m and possibly 12 m x 15 m, 12 m x 16 m and 14 m x 16 m.

Model: **Toro TR 2**
Jet size(s): No. 11
Test pressure: 345 kPa
Flow rate: 22 litres/minute
Diameter of throw: 26.2 metres

Results

Four tests were conducted on the Toro TR2 sprinkler with a size 11 jet at an operating pressure of 345 kPa for average wind speeds between 5.8 and 16.9 km/hour. The wind speed data measured during each test on this sprinkler is shown in Table 2.26.

Table 2.26. Prevailing wind speed and wind direction during testing of Toro TR2 single nozzle No. 11

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
152	5.8	14.0	0	0.9	160	75
87	9.7	26.6	0.4	1.0	136	37
199	14.4	27.4	4.7	1.3	201	16
20	16.9	32.8	6.1	1.5	77	16

Square configuration

The Toro TR 2 with a single nozzle No.11 when spaced at 12 m x 12 m had a DU above 75 per cent (minimum acceptable level) at all wind speeds tested. However the SC was below 1.4 (maximum acceptable level) only for wind speeds up to 10 km/hour (Figure 2.90). For all other square spacings tested this sprinkler had an unacceptable uniformity at all but low wind speeds.

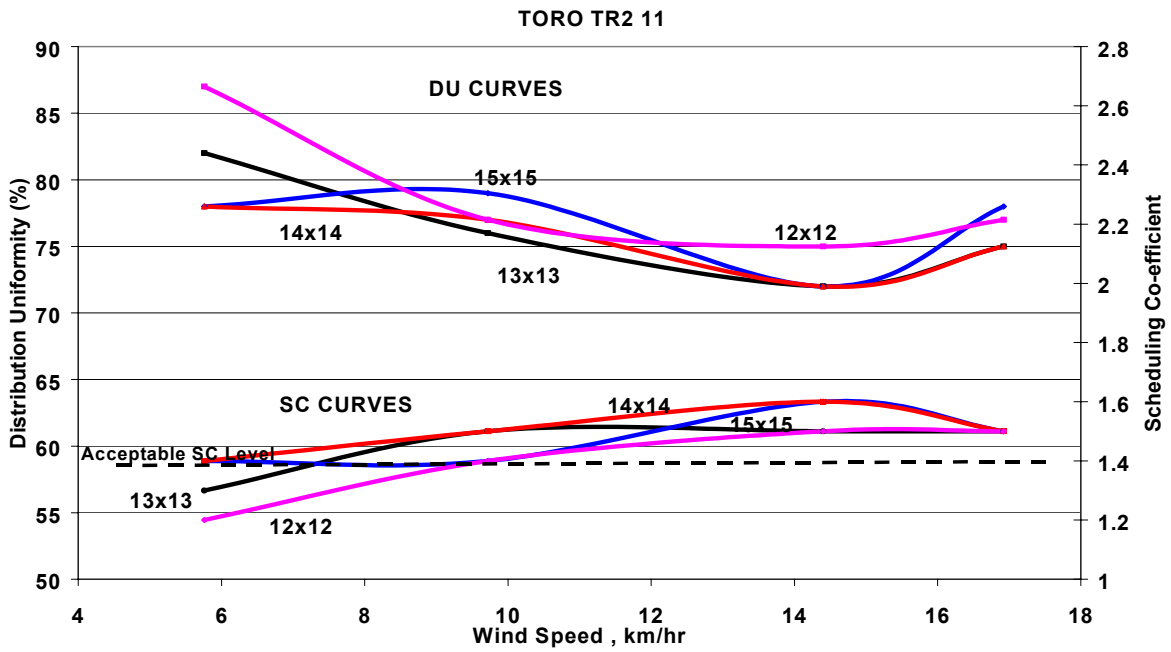


Figure 2.90. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

When spaced at 9 m x 14 m this sprinkler had DU's above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.91 and Figure 2.92). At a spacing of 12 m x 14 m this sprinkler had a DU that was marginal at moderate wind speeds (DU=75 per cent), however the SC increased above 1.4. At all other spacings the DU fell below 75 per cent and the SC increased above 1.4 as wind speed increased.

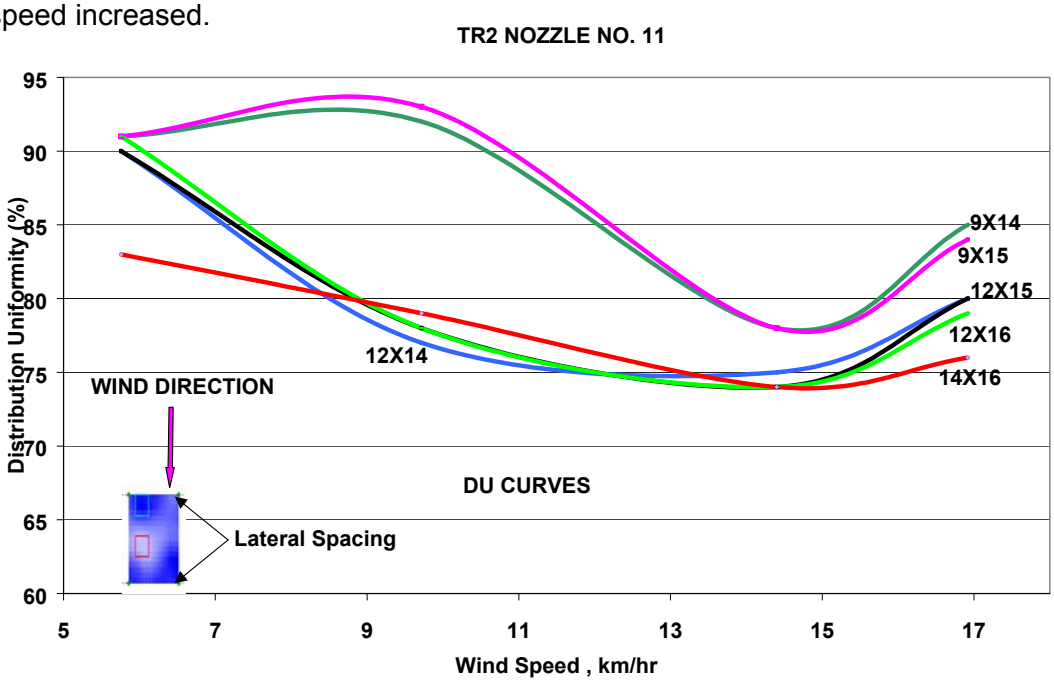


Figure 2.91. Effect of wind speed on distribution uniformity in rectangular configuration.

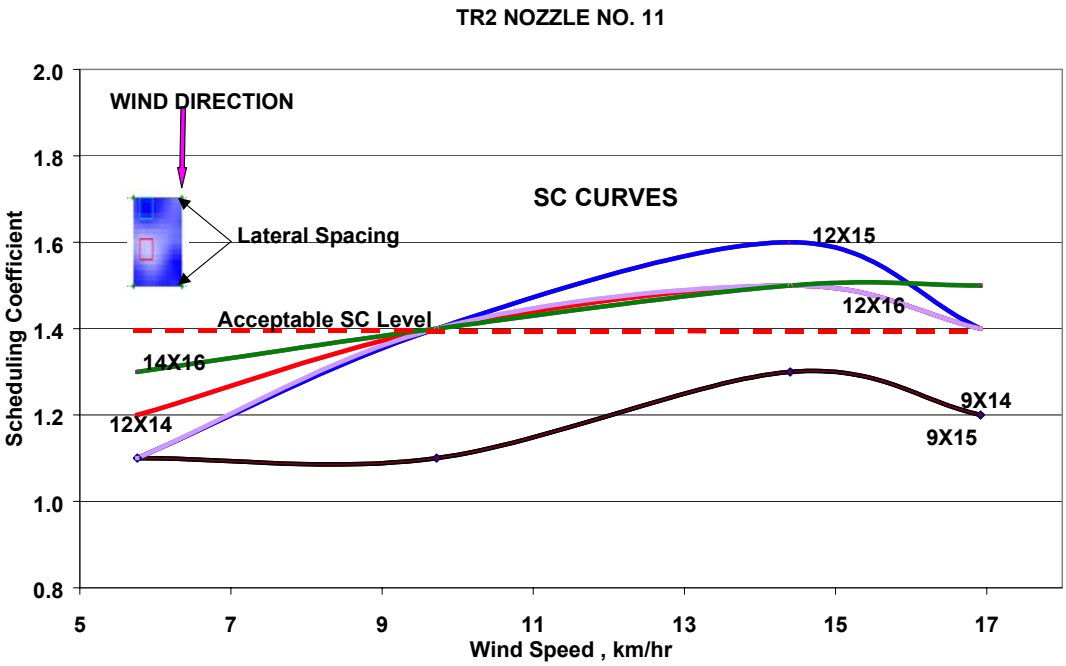


Figure 2.92. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: Possibly 12 m x 12 m.
Rectangular configuration: 9 m x 14 m and 9 m x 15 m.

Model: **Toro TR 2**
Jet size(s): No. 11 x 6
Test pressure: 379 kPa
Flow rate: 31 litres/minute
Diameter of throw: 28.4 metres

Results

Five tests were conducted on the Toro TR2 sprinkler with size 11 x 6 jets at an operating pressure of 379 kPa for average wind speeds between 8.3 and 16.2 km/hour. The wind speed data measured during each test on this sprinkler is shown in Table 2.27.

Table 2.27 Prevailing wind speed and wind direction during testing of Toro TR 2 - double nozzle No. 11 x 6

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
36	8.3	16.2	0.4	1.0	166	43
180	9.4	19.1	2.9	1.0	60	26
37	12.2	21.6	5.0	1.1	225	23
35	13.7	24.8	2.5	1.2	235	20
21	16.2	32.8	3.6	1.5	74	20

Square configuration

The Toro TR2 with double nozzles No.11 x 6 when spaced at 12 m x 12 m and 14 m x 14 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) for wind speeds below 16 km /hour (Figure 2.93). When spaced at 15 m x 15 m this sprinkler had an marginal uniformity across the range of wind speeds tested (the SC was equal to 1.4). When spaced at 16 m x 16 m the uniformity was unacceptable once the wind speed increased.

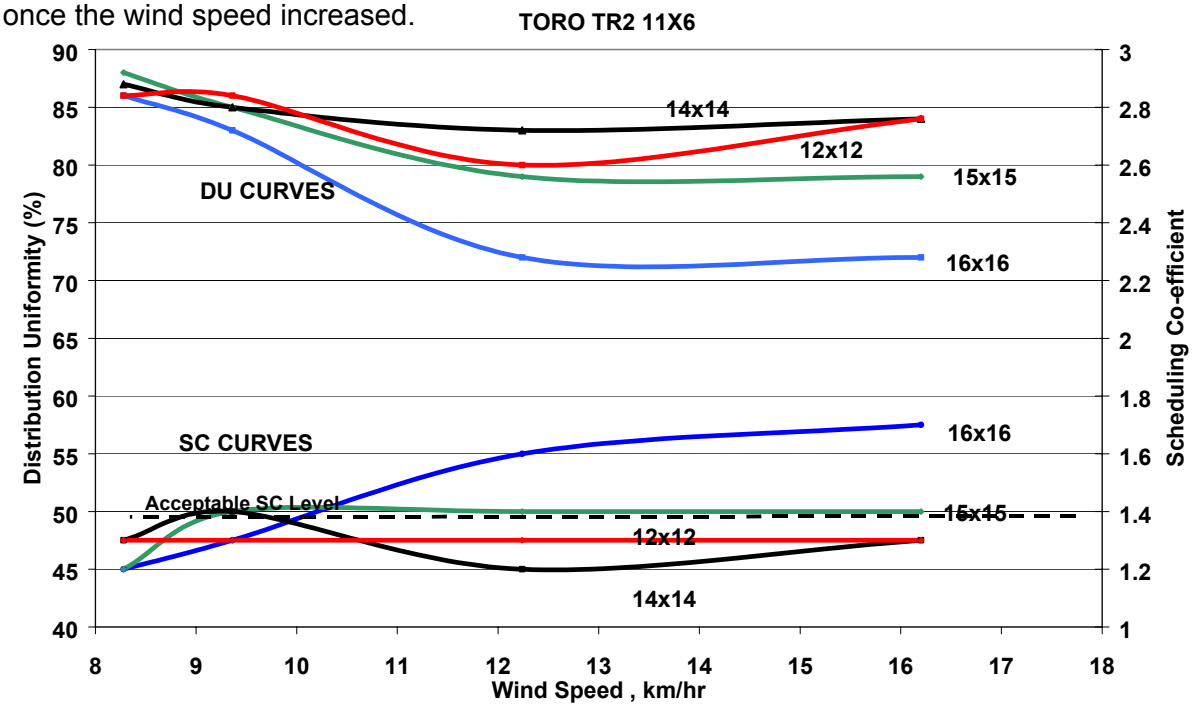


Figure 2.93. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

When spaced at 9 m x 14 m, 9 m x 15 m, 12 m x 14 m and 12 m x 15 m this sprinkler had DU's above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.94 and Figure 2.95). At spacings of 12 m x 16 m and 14 m x 16 m, the SC increased above 1.4 as wind speed increased.

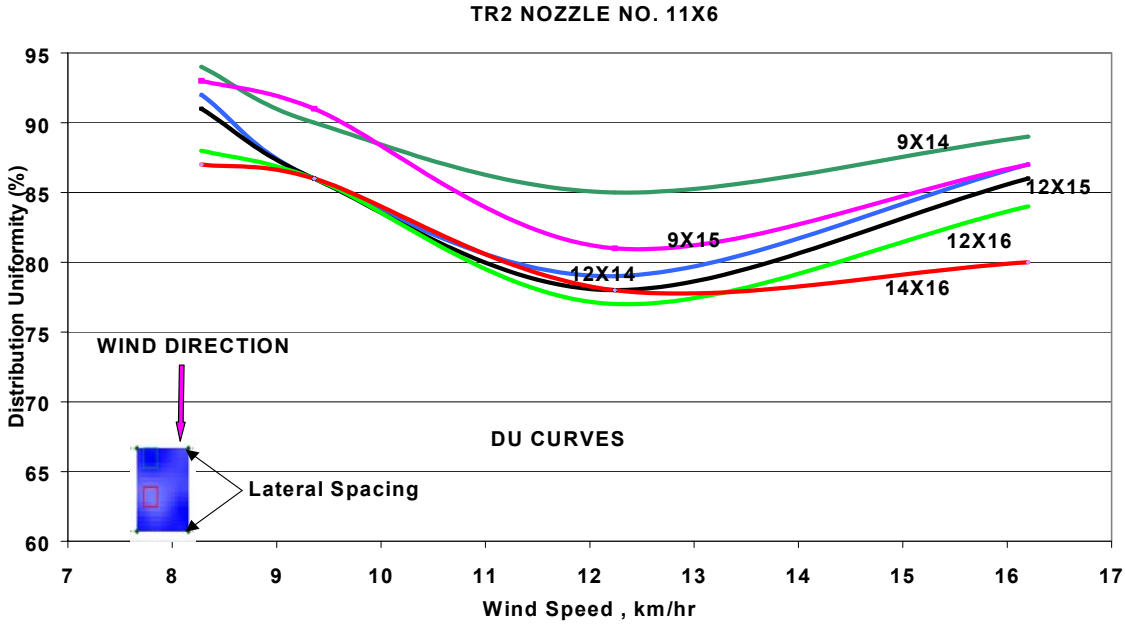


Figure 2.94 Effect of wind speed on distribution uniformity in rectangular configuration.

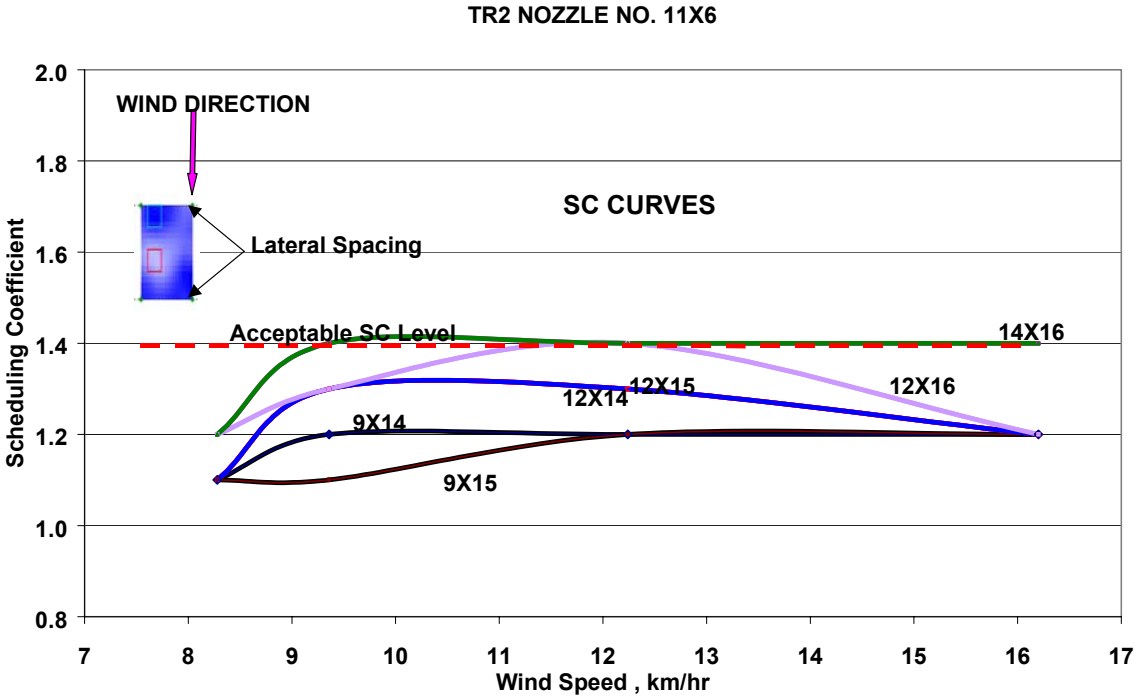


Figure 2.95 Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m, 14 m x 14m and possibly 15 m x 15 m.
Rectangular configuration: 9 m x 14 m, 9 m x 15 m, 12 m x 14 m and 12 m x 15 m.

Model: **Toro TR 2**
Jet size(s): No. 14
Test pressure: 379 kPa
Flow rate: 38 litres/minute
Diameter of throw: 26.5 metres

Results

Five tests were conducted on the Toro TR2 sprinkler with a size 14 jet at an operating pressure of 379 kPa for average wind speeds between 7.6 and 14.0 km/hour. The wind speed data measured during each test on this sprinkler is shown in Table 2.28.

Table 2.28 Prevailing wind speed and wind direction during testing of Toro TR 2 - single nozzle No. 14

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
49	7.6	19.1	0.4	1.1	248	64
179	8.3	16.2	2.2	0.9	70	19
64	10.4	21.6	4.0	0.9	253	21
38	11.5	20.2	6.5	0.9	98	17
65	14.0	24.1	7.2	1.0	235	17

Square configuration

Insufficient sprinkler tests were conducted at high wind speeds (> 14 km/hour) on the Toro TR 2 sprinkler with a single nozzle size 14. When spaced at 12 m x 12 m this sprinkler had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) for wind speeds below 9 km/hour (Figure 2.96). At all other spacings tested, the DU fell below 75 per cent and the SC increased above 1.4.

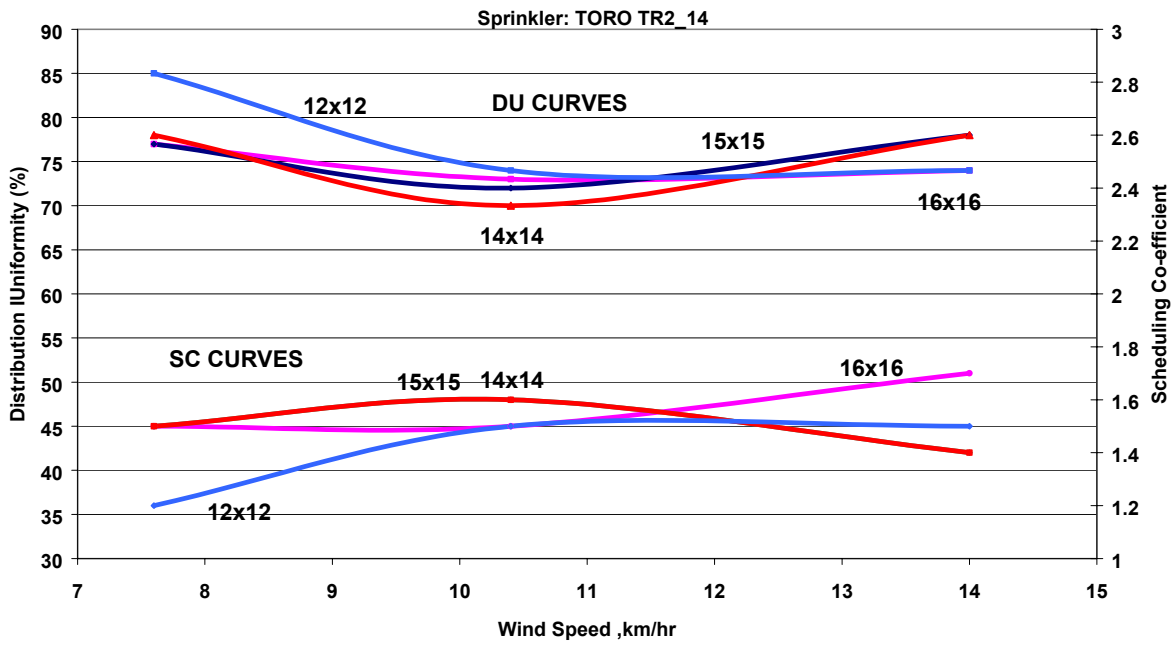


Figure 2.96. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

Insufficient sprinkler tests were conducted on the Toro TR 2 sprinkler with a single nozzle size 14 at high wind speeds (> 14 km/hour). When spaced at 9 m x 14 m and 9 m x 15 m

this sprinkler had DU's considerably above 75 per cent (minimum accpetable level) and SC's considerably below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.97 and Figure 2.98). At all other spacings the DU decreased to near 75 per cent and the SC increased near to 1.4 at a wind speed of 14 km/hour.

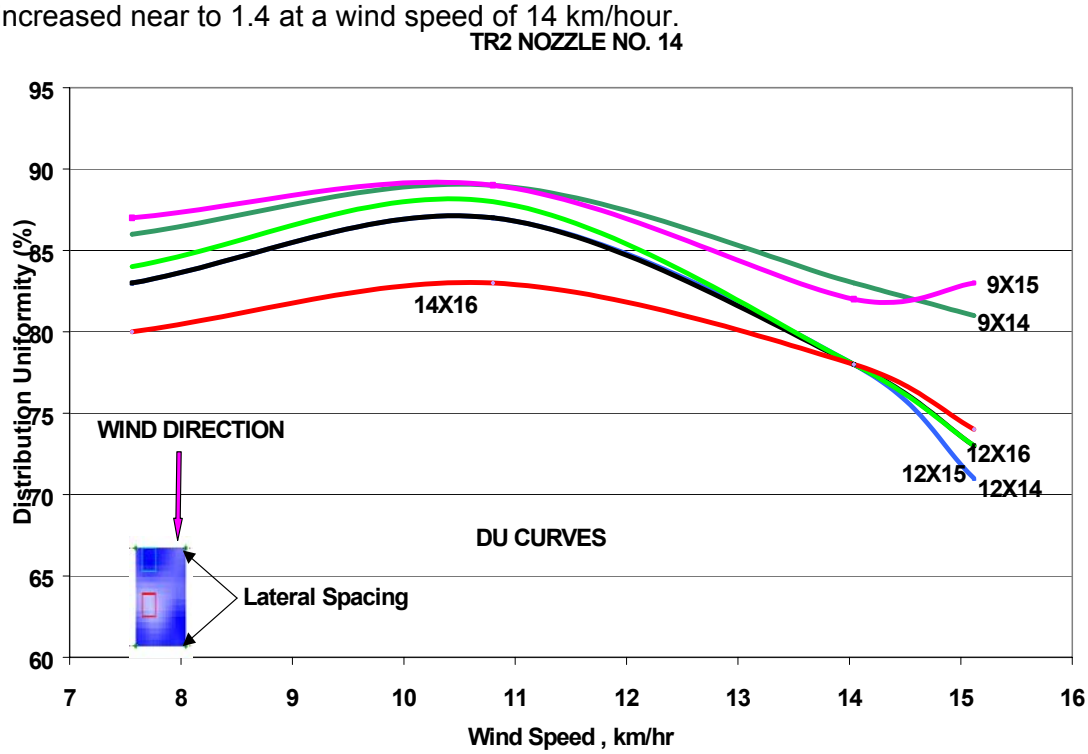


Figure 2.97. Effect of wind speed on distribution uniformity in rectangular configuration.

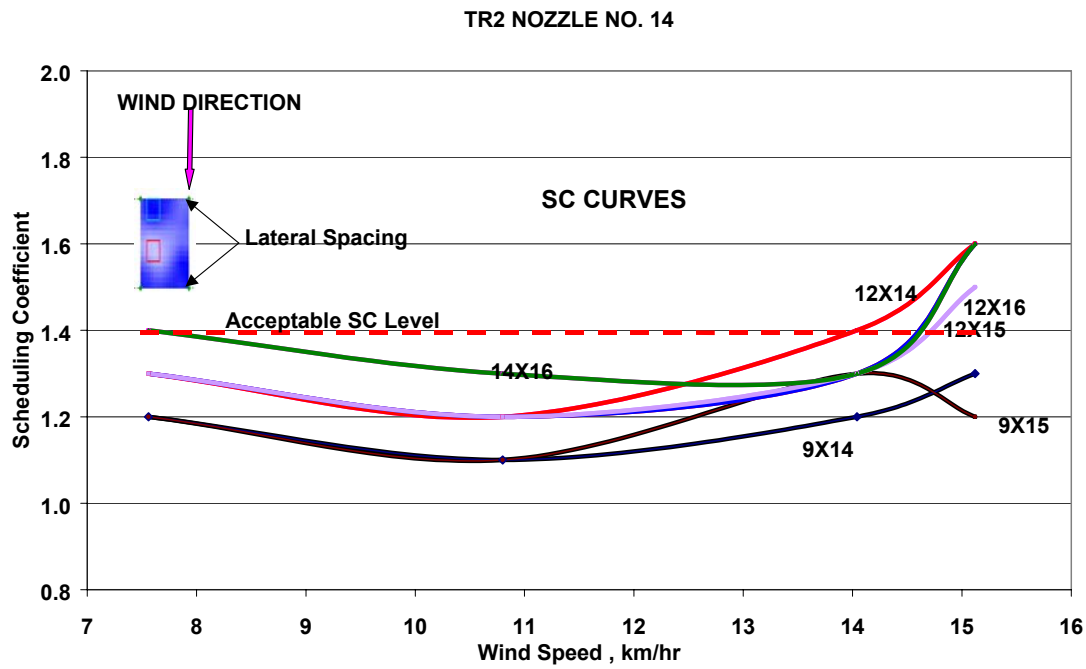


Figure 2.98. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: Possibly 12 m x 12 m
Rectangular configuration: 9 m x 14m and 9 m x 15 m

Model: **Toro TR 2**
Jet size(s): No. 14 x 8
Test pressure: 379 kPa
Flow rate: 51 litres/minute
Diameter of throw: 31.7 metres

Results

Five tests were conducted on the Toro TR2 sprinkler with size 14 x 8 jets at an operating pressure of 379 kPa for average wind speeds between 6.8 and 18.0 km/hour. The wind speed data measured during each test on this sprinkler is shown in Table 2.29.

Table 2.29 Prevailing wind speed and wind direction during testing of Toro TR 2 - double nozzle No. 14 x 8

Test no.	Average wind speed (km/hr)	Maximum wind speed (km/hr)	Minimum wind speed (km/hr)	S.D of wind speed	Average wind direction (degrees)	S.D of wind direction
63	6.8	12.6	2.5	0.7	264	35
138	7.9	16.6	0	1.1	89	46
119	11.5	24.1	3.6	1.1	240	19
198	15.5	28.8	7.2	1.1	185	14
148	18.0	26.6	7.9	1.3	207	13

Square configuration

The Toro TR 2 double nozzle No.14 x 8 when spaced at 12 m x 12 m and 13 m x 13 m had a DU above 75 per cent (minimum acceptable level) and a SC below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.99). When spaced at 14 m x 14 m this sprinkler had an unacceptable uniformity when wind speed increased above 16 km/hour. When spaced at 15 m x 15 m the uniformity was poor except at low wind speeds.

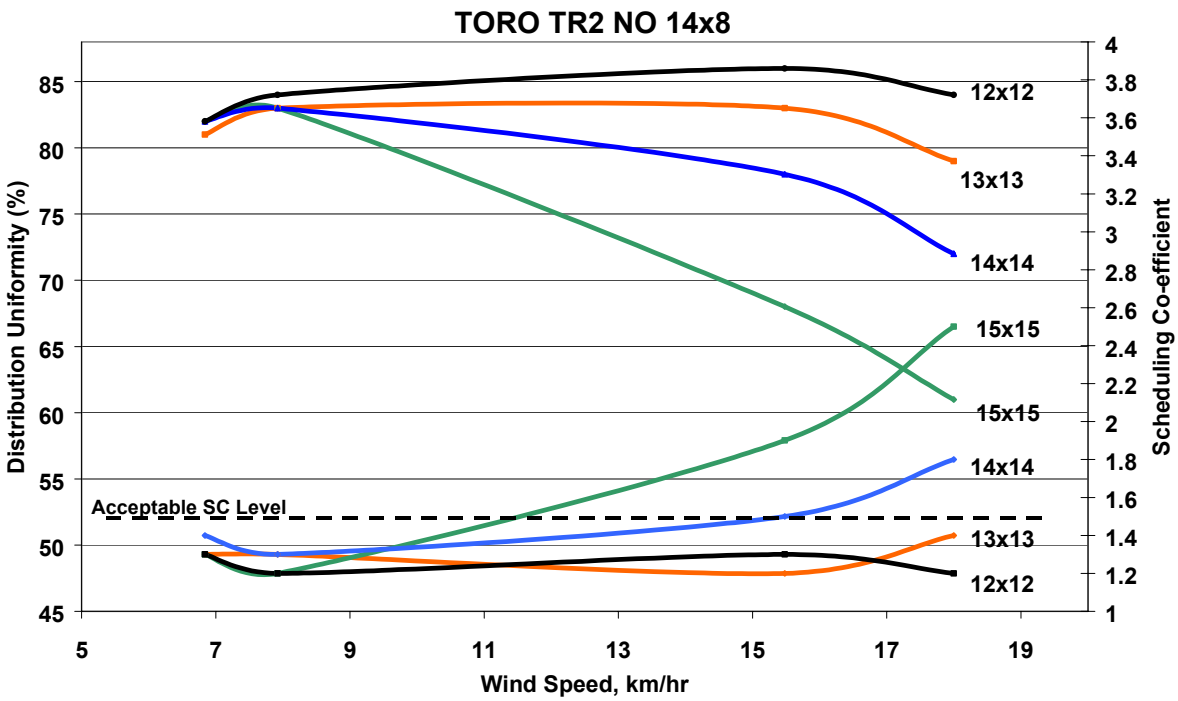


Figure 2.99. Effect of wind speed on distribution uniformity and scheduling coefficient.

Rectangular configuration

When spaced at 9 m x 14 m and 9 m x 15 m this sprinkler had DU's above 75 per cent (minimum acceptable level) and SC's below 1.4 (maximum acceptable level) for all wind speeds tested (Figure 2.100 and Figure 2.101). At a spacing of 12 m x 14 m this sprinkler had an acceptable uniformity (SC < 1.4) for wind speeds below 13 km/hour. At all other spacings the DU fell below 75 per cent and the SC increased above 1.4 as wind speed increased.

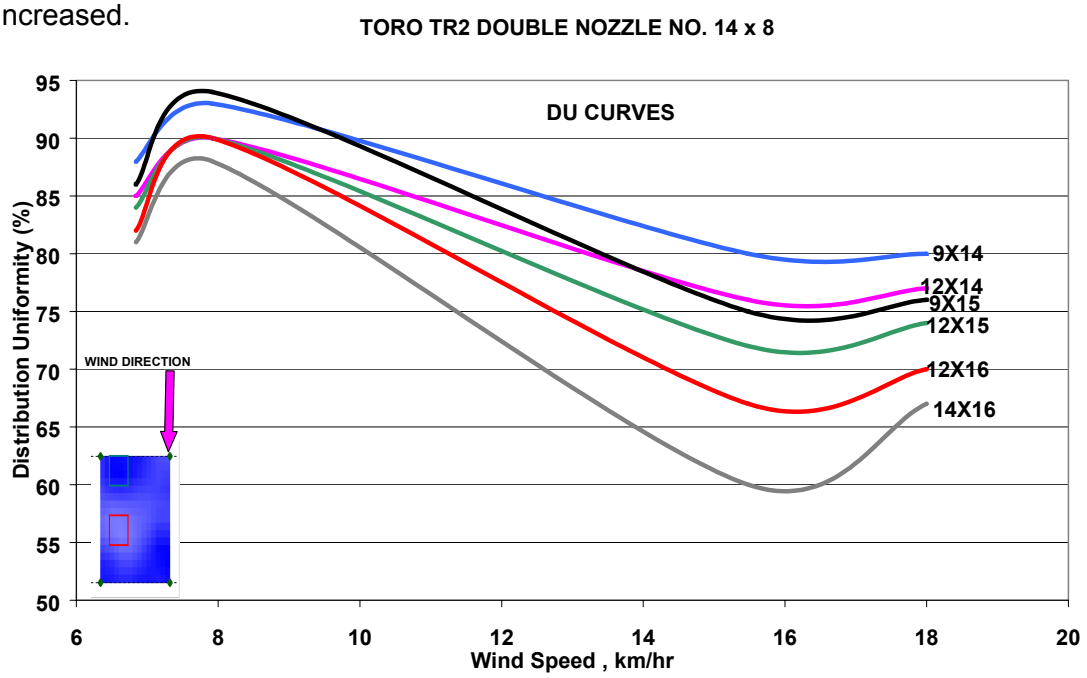


Figure 2.100. Effect of wind speed on distribution uniformity in rectangular configuration.

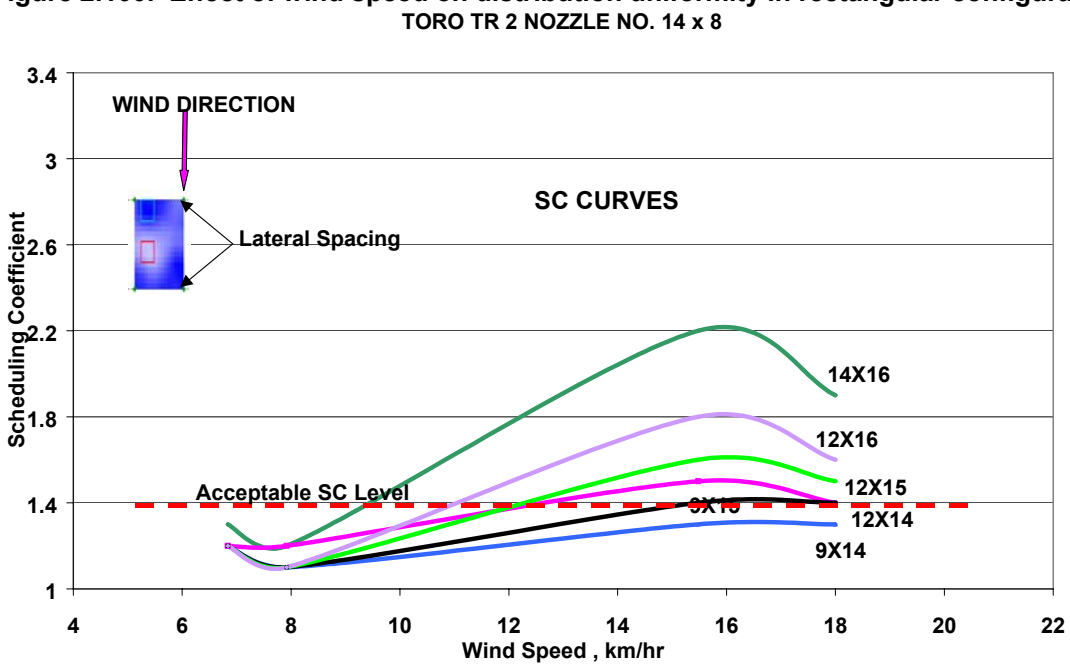


Figure 2.101. Effect of wind speed on scheduling coefficient in rectangular configuration.

Recommended spacing for windy conditions

Square configuration: 12 m x 12 m and 13 m x 13 m.
Rectangular configuration: 9 m x 14 m and 9 m x 15 m.

2.4 References

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3. IRRIGATION AND NITROGEN REQUIREMENTS OF A SUMMER GROWN CABBAGE CROP

Abstract

The nitrogen and irrigation requirements of cabbage on a Karrakatta sand were examined using a line source trial. Weekly crop harvests allowed the development of crop factors and optimum nitrogen rates for each week of the crops life. Data is provided on the irrigation and nitrogen required to achieve 99 per cent and 95 per cent of maximum yield. It is recommended that the nitrogen rate required for 95 per cent of maximum yield be used on the Swan Coastal Plain because of concerns about nitrate enrichment of the ground water.

The percentage of evaporation replacement required increased from 100 per cent in week 2 to 137 per cent in the week prior to harvest. The weekly rate of nitrogen required increased from 31 kg N/ha in week 2 to around 72 kg N/ha from week 5 onwards. A total of 410 kg N/ha/crop was required over the life of the crop for 95 per cent of maximum yield. 570 kg N/ha/crop was required over the life of the crop for 99 per cent of maximum yield.

Low tension tensiometers were used to measure soil water status in each irrigation treatment. Comparing soil moisture with the weekly crop yield data showed that the critical soil moisture tension for cabbage on a Karrakatta sand is approximately - 4.5 centibars.

Lysimeters were installed to allow a water and nutrient balance to be conducted over the life of the crop. At the optimum nitrogen and irrigation rate approximately 70 per cent of the water and 50 per cent of the nitrogen applied was leached past the root zone and collected in the lysimeters. These loss rates demonstrate the poor water and nitrogen use efficiency that is achievable on the coastal plain sands when vegetable crops are watered twice daily with overhead sprinklers and fertiliser is applied weekly.

3.1 Introduction

Nitrogen and water use efficiency by vegetable growers on the Swan Coastal Plain, Western Australia is generally poor (Hegney and McPharlin, 1997, Galati and McKay, 1996). The soils of the plain are medium to coarse sands that have a poor ability to hold both water and nitrogen fertiliser. Growers apply large amounts of nitrogen fertiliser as compared to other vegetable growing areas in the world and high concentrations of nitrate are often found in the ground water below horticultural properties (Lantzke, 1997). Vegetable crops are usually irrigated daily or twice daily by overhead sprinklers at about 150 per cent of pan evaporation. Monitoring studies have shown that with current industry practice around half of the irrigation and nitrogen that is applied is leached past the root zone (Sharma, 1991).

The nitrogen and irrigation requirements of vegetables increase as the crop matures. Many vegetable growers apply a flat rate of nitrogen and water throughout the crops life. Applying nitrogen and water at rates that more closely match crop demand can increase nitrogen and water use efficiency. Harvesting plants each week and determining the minimum amount of water and nitrogen necessary for maximum growth allows crop factors and nitrogen rates for each week of the crop life to be determined. In the following trial this was accomplished using a line source irrigation design. A line source trial also allows the interaction between irrigation and nitrogen rate to be examined.

Aim

1. To develop crop factors and nitrogen application rates that are necessary for maximum yield of summer grown cabbage on sandy soils.
2. To determine, using logging tensiometers the critical soil moisture tension at which cabbage plants become stressed and yield declines.
3. To carry out a nitrogen and water balance on the crop.

3.2 Method

The trial was conducted at Medina Research Centre on a Yellow Karrakatta Sand. The site was surrounded by a windbreak to reduce the effect of wind on the sprinkler irrigation pattern.

Site preparation

Seven days before planting the following fertilisers were broadcast and incorporated by rotary hoe to 150-200 mm depth: superphosphate at 2000 kg/ha, potassium sulphate at 300 kg/ha, magnesium sulphate at 100 kg/ha and trace elements (150 kg/ha). Metham sodium was applied at 500 l/ha the same day as fertiliser incorporation. The seedling trays were drenched with 1ml/l Rovral plus a nutrient solution containing Polyfeed 19:19:19 at 10 gms/litre on day of transplanting.

Planting

Cabbage seedlings (cv. Arixos) were planted on Wednesday 1 December 1999 at a spacing of 2 rows per bed with 400 mm between rows and 350 mm between plants. Each plot was 9 m long and 1.5 m wide.

All the plots were irrigated three times per day for three days to a total of 9 mm per day using three lines of sprinklers to ensure uniform establishment. On Friday, 3 December, 25 kg/ha Polyfeed 19:19:19 was applied by boomspray to all plots. This was to ensure uniform establishment.

Irrigation and nitrogen treatments

Irrigation and nitrogen treatments were commenced at day 7. A line source irrigation system (Hanks *et al*. 1976) was set up down the middle of the trial area. Irrigation rate decreased with increasing distance from the line source. This results in a range of irrigation treatments running parallel to and either side of the line source. Five blocks of nitrogen rates were applied across the irrigation treatments. There were four replicates.

The irrigation rates were:	W6	60 per cent of the previous days evaporation
	W5	85 per cent of the previous days evaporation
	W4	120 per cent of the previous days evaporation
	W3	145 per cent of the previous days evaporation
	W2	170 per cent of the previous days evaporation
	W1	175 per cent of the previous days evaporation

Irrigation was applied in two applications per day at 9 a.m. and at 2 p.m. Rain gauges were installed across the irrigation treatments in two locations. These volumes collected were recorded daily.

The nitrogen rates were:

N0	0	kg N/ha/week
N1	25	kg N/ha/week
N2	50	kg N/ha/week
N3	75	kg N/ha/week
N4	100	kg N/ha/week

In total eight weekly applications of nitrogen were applied to each plot. The source of nitrogen was as ammonium nitrate and it was applied to all plots by watering can. The fertiliser was washed off the leaves to prevent fertiliser burn.

Lysimeters

Six mini drainage lysimeters were installed below each of the irrigation rates on the N3 fertiliser treatment. A further four lysimeters were installed within the W4 irrigation treatment below the N0, N1, N2 and N4 fertiliser plots. The lysimeters were pumped out each week prior to fertilising and the volume and nitrogen concentration in the lysimeter recorded.

Tensiometers

Two tensiometers fitted with a pressure transducer (Irrometer LT®) were installed in each of the six irrigation treatments (N3 fertiliser rate) at depths of 15 cm and 30 cm. Soil moisture suction was recorded continuously over the life of the trial using a datalogger. The crop factors required for maximum growth could then be related to soil moisture tension allowing recommendations on the critical soil moisture suction at which cabbage yield declines to be determined.

3.3 Results and discussion

Effect of irrigation and nitrogen on yield

Figures 3.1 to 3.7 show the effect of irrigation and nitrogen on total cabbage yield for each week of the crops life. Table 3.1 gives the irrigation and nitrogen rate required for each week of the crops life in order to achieve 99 per cent of maximum yield. Table 3.2 gives the irrigation and nitrogen rate required for each week of the crops life in order to achieve 95 per cent of maximum yield. No yield data was collected in week 7 because heavy rainfall fell during that week.

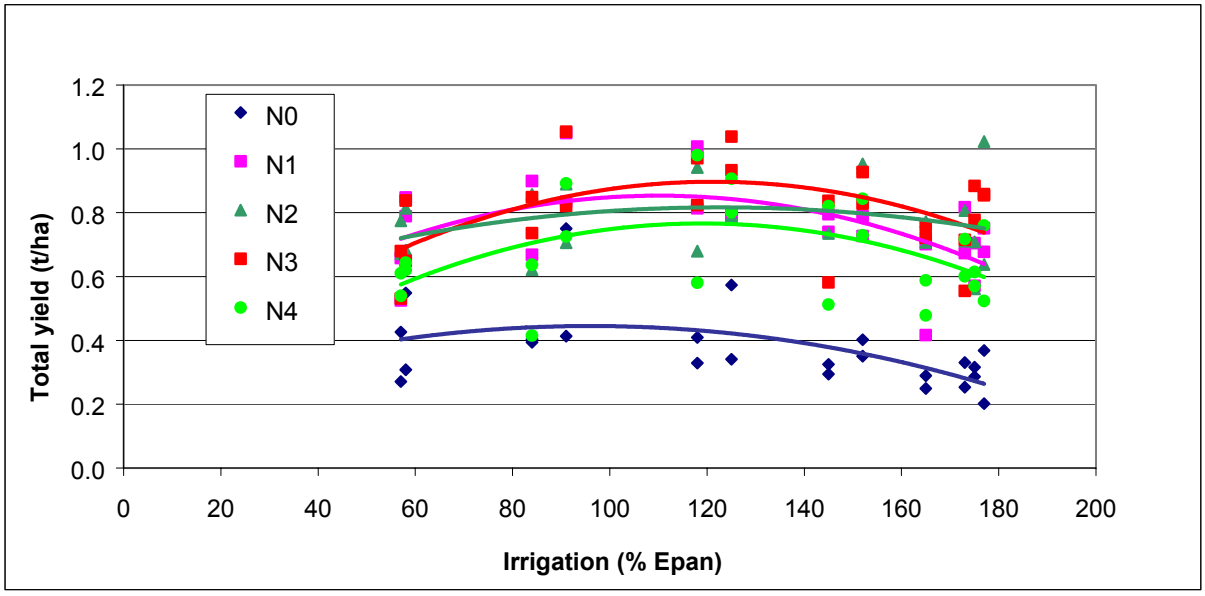

Figure 3.1. Effect of irrigation on cabbage yield - Week 2.

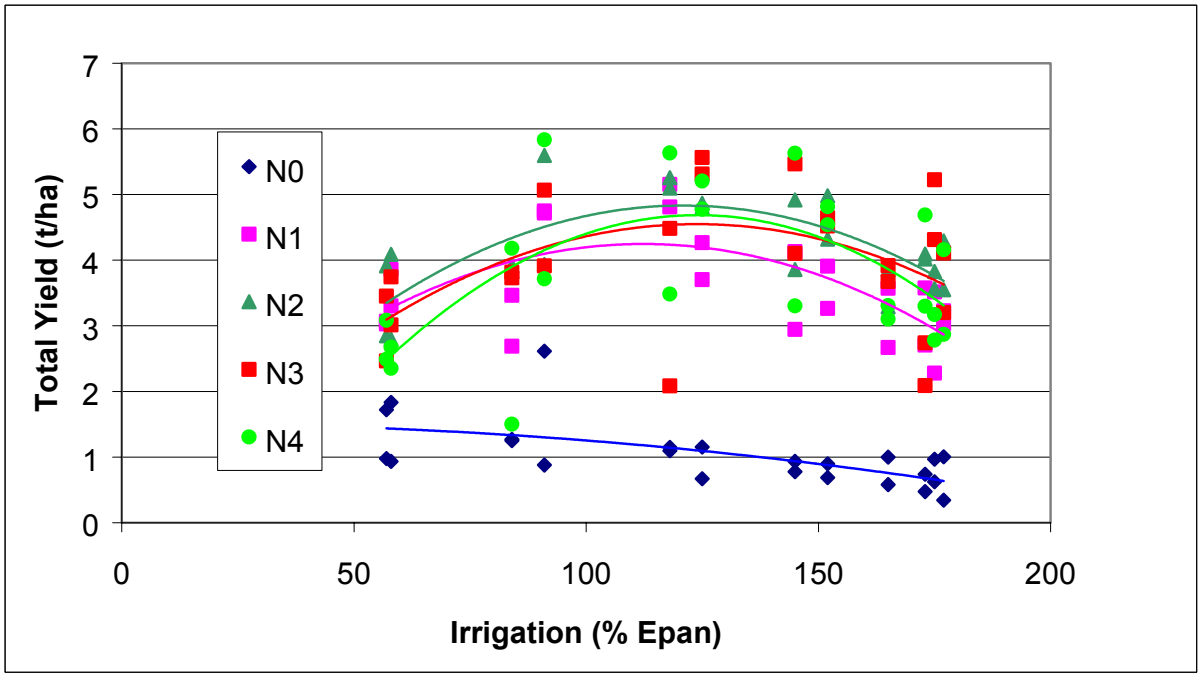

Figure 3.2. Effect of irrigation on cabbage yield - Week 3.

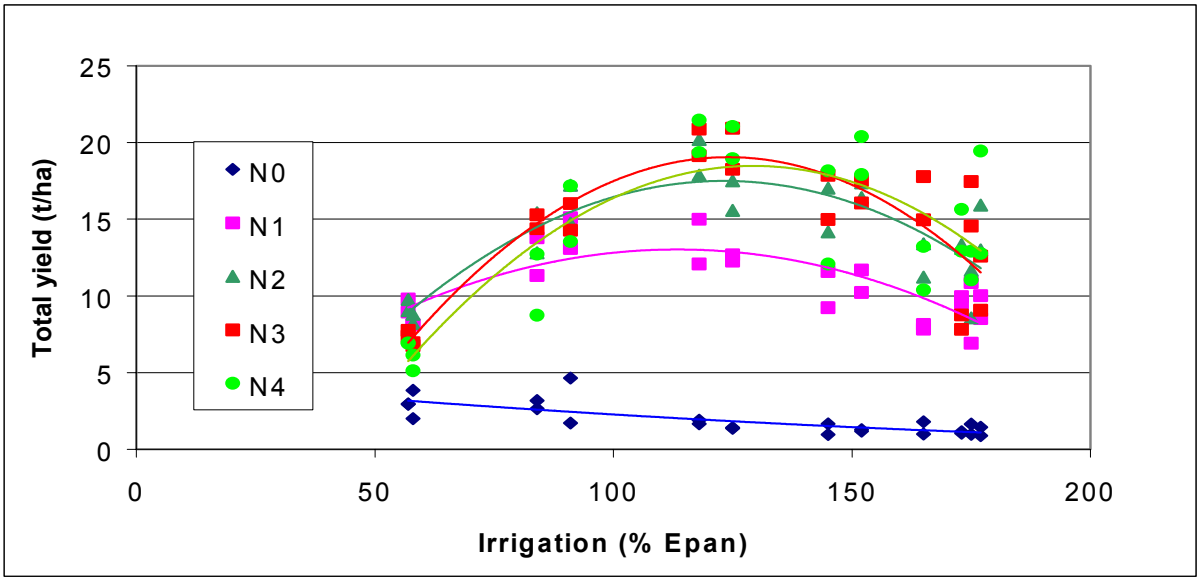

Figure 3.3. Effect of irrigation on cabbage yield - Week 4.

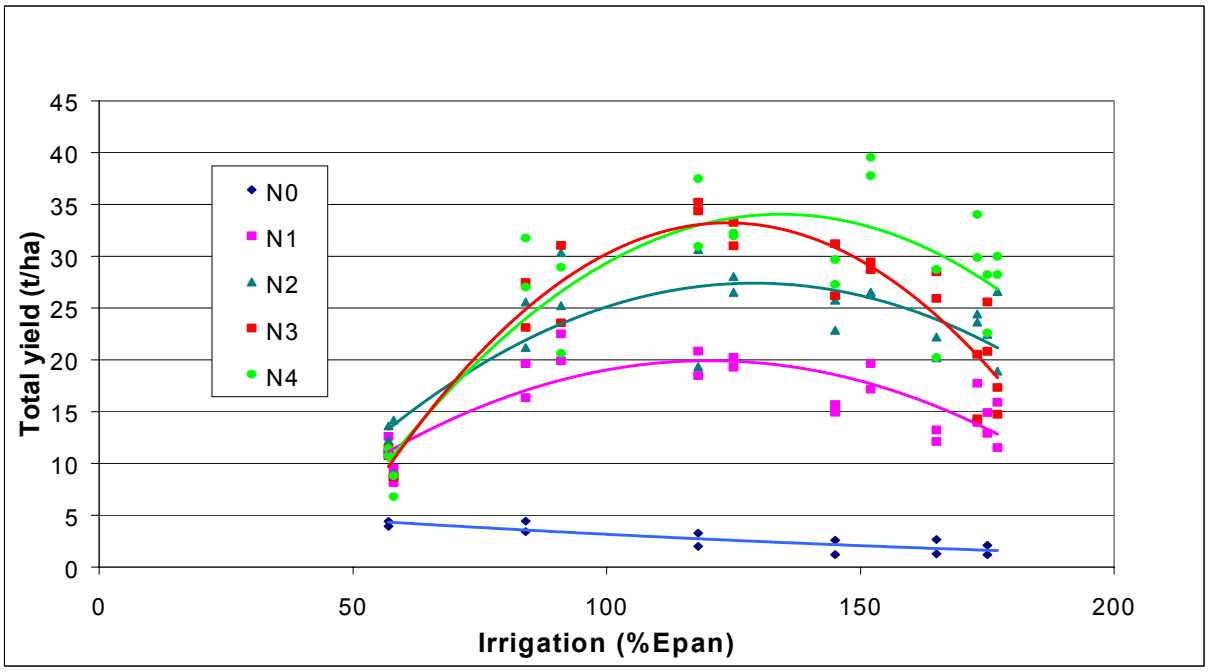

Figure 3.4. Effect of irrigation on cabbage yield - Week 5.

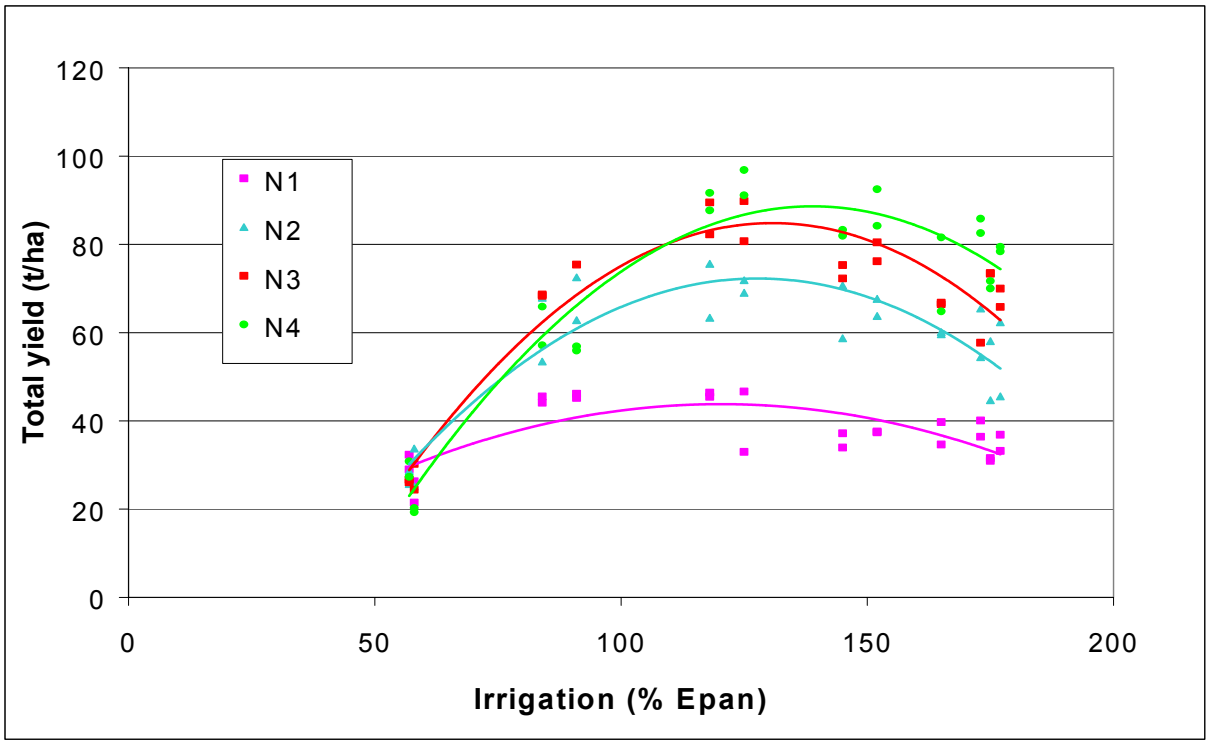

Figure 3.5. Effect of irrigation on cabbage yield - Week 6.

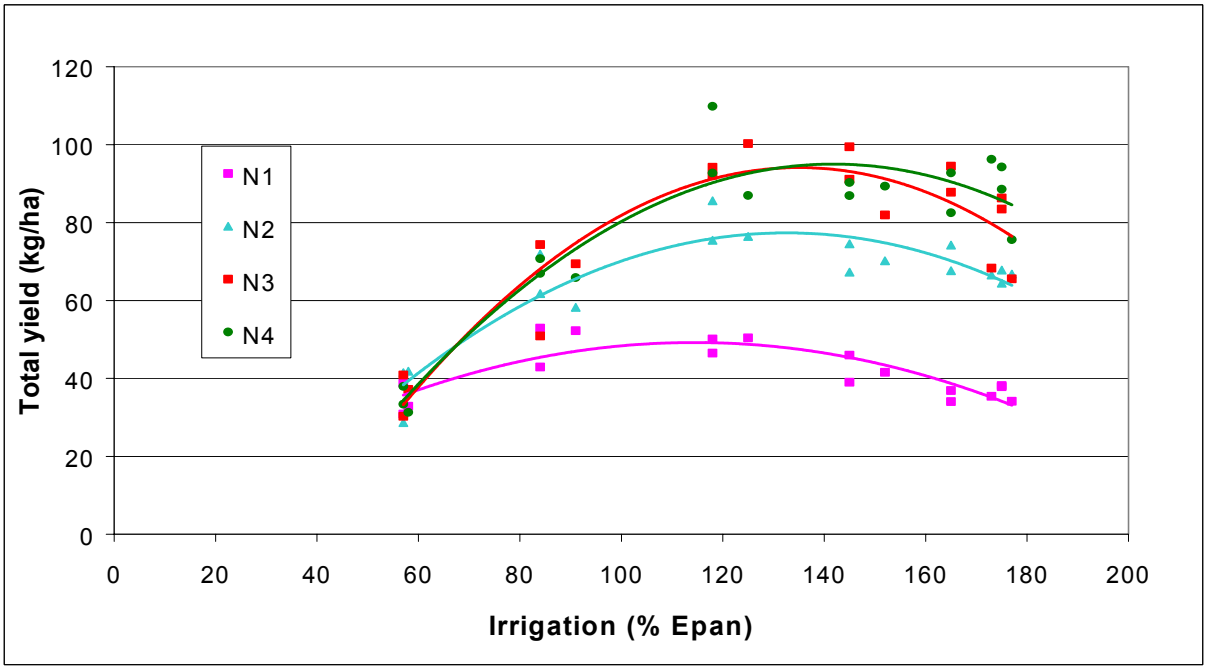

Figure 3.6. Effect of irrigation on cabbage yield - Week 8.

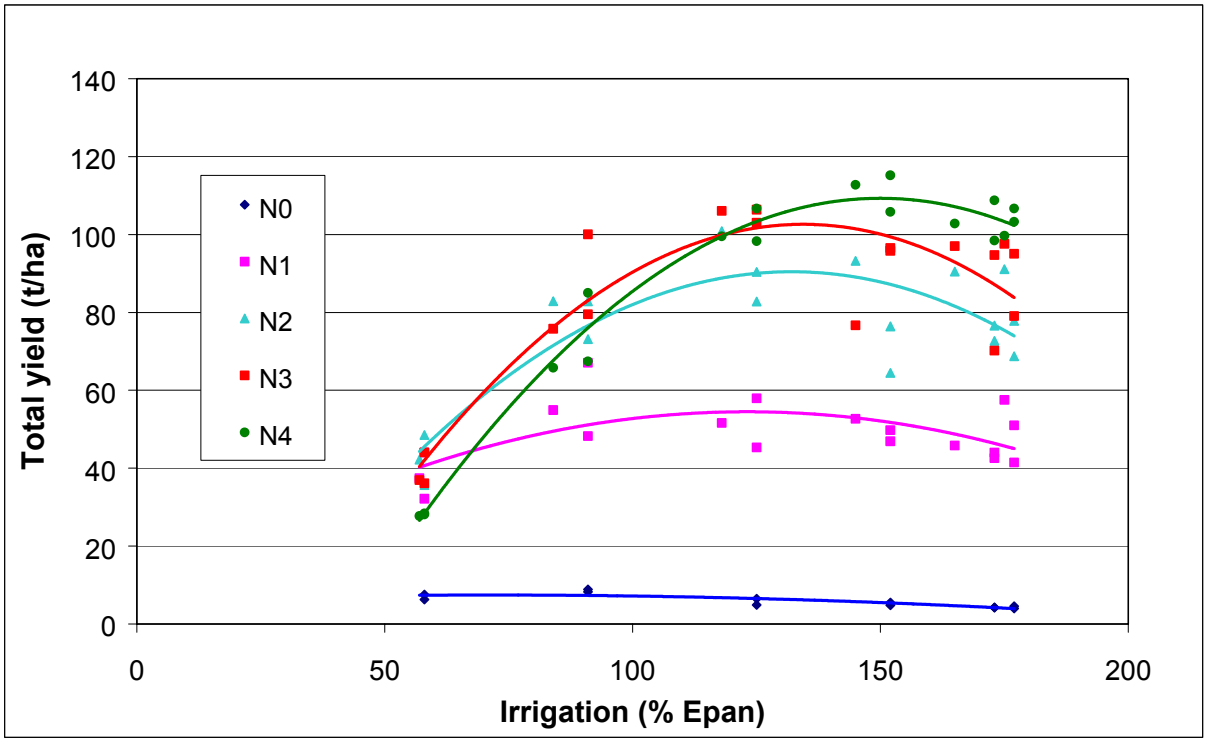

Figure 3.7. Effect of irrigation on cabbage yield - Week 9.

Table 3.1 Irrigation and nitrogen requirements for 99 per cent of maximum yield in each week of the cabbages' life

	Week 2 (15/12/99)	Week 3 (22/12/99)	Week 4 (29/12/99)	Week 5 (05/01/00)	Week 6 (12/01/00)	Week 8 (25/01/00)	Week 9 (02/02/00)
Optimum irrigation (% Epan)	100	111	116	125	133	136	143
Optimum nitrogen (kg/ha/week)	44	50	63	86	82	82	81
Optimum total yield (t/ha)	0.9	4.7	17.6	32.6	53.1	92.8	105.9

Table 3.2 Irrigation and nitrogen requirements for 95 per cent of maximum yield in each week of the cabbages' life

	Week 2 (15/12/99)	Week 3 (22/12/99)	Week 4 (29/12/99)	Week 5 (05/01/00)	Week 6 (12/01/00)	Week 8 (25/01/00)	Week 9 (02/02/00)
Optimum irrigation (% Epan)	100	106	111	120	129	132	137
Optimum nitrogen (kg/ha/week)	31	35	50	72	72	73	72
Optimum total yield (t/ha)	0.85	4.65	16.9	31.3	50.9	89.0	101.7

Irrigation

The rate of irrigation required for 99 per cent of maximum growth increased from 100 per cent of Epan in week 2 to 143 per cent of Epan in the week prior to harvest (Table 3.1). The irrigation rates to obtain 95 per cent of maximum yield were only slightly lower then those required for 99 per cent of maximum yield (Table 3.2). McKay *et al*. (in prep.) found on the same line source trial site that carrot irrigation requirements increased from 40 per cent of Epan in week 4 to 135 per cent in week 9. Crop factors for the remainder of the carrots life could not be calculated because of rain interfering with the trial. Hegney *et al.* (1997) found that irrigation was required at 150 per cent of Epan for maximum yield of potatoes on Spearwood sand.

Yield decreased at the W2 (170 per cent Epan) and W1 (175 per cent Epan) irrigation rates for all nitrogen rates (Figures 3.1 to 3.7). The cause of this is most likely excessive nitrogen leaching resulting in nitrogen deficiency in the cabbages.

Nitrogen

Tables 3.1 and 3.2 show the amount of nitrogen required for 99 per cent and 95 per cent of maximum growth respectively. It is recommended that the nitrogen rate required for 95 per cent of maximum yield (Table 3.2) be used on most areas of the Swan Coastal Plain because of concerns about nitrate enrichment of the ground water. The weekly rate of nitrogen required increased from 31 kg N/ha in week 2 to around 72 Kg N/ha from week 5 onwards. A total of 410 kg N/ha/crop was required over the life of the crop for 95 per cent of maximum yield. 570 kg N/ha/crop was required over the life of the crop for 99 per cent of maximum yield. To determine the optimum economic rate of fertiliser to apply the cost of the additional nitrogen fertiliser needs to compared to the increase in yield. In 2000, urea cost $260 per tonne or $565 per tonne of nitrogen. An additional 160 kg of nitrogen per hectare will cost approximately $90 per hectare. The increase in yield is likely to offset the small increase in fertiliser. However as suggested earlier for environmental reasons the rate of nitrogen that achieves 95 per cent of maximum yield should be recommended in most areas.

Lantzke (unpublished data) found that cabbages required 800 kg/ha of nitrogen for maximum yield on a Karrakatta sand. However in this trial nitrogen was applied in a flat rate throughout the crops life and potential savings in fertiliser early in the crops life were not investigated. The rate required to achieve 95 per cent of maximum yield (410 kg/ha) is consistent with the current Department of Agriculture Western Australia recommendation of 420 kg/ha.

Tensiometer readings

Figures A.1 to A.8 in Appendix 1 show the tensiometer readings from week 2, when the treatments were first applied, until harvest. The critical soil moisture content at which cabbage yield begins to decline can be estimated by comparing this data with the weekly yield data (Table 3.1).

Figures A.1 and A.2 show the tensimeter readings in each irrigation treatment from 8/12/99 until 22/12/99 (weeks 2 and 3) for the 15 cm deep and 30 cm deep tensiometers respectively. It can be seen in that the tensiometers in the W6 (60 per cent Epan) and W5 (85 per cent Epan) treatments give readings below those of the other treatments (the 15 cm deep tensiometer in the W5 irrigation treatment was faulty and the reading was not included in Figure A.1). The weekly yield data (Table 1) shows that at week 2 (15/12/99) and week 3 (22/12/99) 100 per cent of Epan and 111 per cent of Epan respectively was required for maximum growth. The W5 and W6 treatments had soil moisture tensions below - 4.5 cb while the other irrigation treatments have soil moisture tensions that were generally above -

4.5 cb. It appears that the critical soil moisture tension for cabbage grown on the sands of the Swan Coastal Plain is approximately - 4.5cb.

Figures A.3 and A.4 show the tensimeter readings in each irrigation treatment from 22/12/99 until 5/1/00 (weeks 4 and 5) for the 15 cm deep and 30 cm deep tensiometers respectively. The tensiometers in the W6 (60 per cent Epan) and W5 (85 per cent Epan) treatments continue to give low readings. The 15cm tensiometer reading for the W4 (120 per cent Epan) treatment begins to fall below the critical soil moisture tension of - 4.5 cb during this period (Figure A.3). Table 1 shows that in the week 4 (22/12/99) and week 5 (29/12/99) 116 per cent and 125 per cent of Epan respectively is required for maximum growth. The W4 irrigation rate becomes insufficient during this period which is highlighted by the falling tensiometer readings.

Figures A.5 and A.6 show the tensimeter readings in each irrigation treatment from 5/1/00 until 19/1/00 (weeks 6 and 7) for the 15 cm deep and 30 cm deep tensiometers respectively. The tensiometers in the W6 (60 per cent Epan), W5 (85 per cent Epan) and W4 (120 per cent Epan) treatments continue to give low readings. The tensiometers in the W3 (145 per cent Epan), W2 (170 per cent Epan) and W1 (175 per cent Epan) treatments continue to give readings above the critical level of - 4.5 cb. The weekly yield data (Table 1) shows that for this time period (week 6) 133 per cent of Epan is required for maximum yield. This data corresponds well to the tensiometer data.

Figures A.7 and A.8 show the tensimeter readings in each irrigation treatment from 19/1/00 until 2/2/00 (weeks 8 and 9) for the 15 cm deep and 30 cm deep tensiometers respectively. The tensiometers in the W6 (58 per cent Epan), W5 (95 per cent Epan) and W4 (120 per cent Epan) treatments continue to give low readings. The tensiometers in the W3 (145 per cent Epan), W2 (170 per cent Epan) and W1 (175 per cent Epan) treatments continue to give readings above the critical level of - 4.5 cb. The weekly yield data (Table 3.1) shows that for this time period 136 per cent (week 8) and 143 per cent (week 9) of Epan is required for maximum yield.

The drying out of all plots on the 25/1/00 was due to the method of irrigation scheduling. Irrigation was scheduled using the previous days evaporation. Using this method will result in under irrigation when a hot windy day with high evaporation is preceded by a mild day with low evaporation. The 25/1/00 had 8.8 mm of evaporation while the previous two days had 6.4 mm and 4.2 mm of evaporation.

The tensiometers were accurate however an unacceptable number of the pressure transducers supplied by the tensiometer manufacturer broke down and had to be discarded. The tensiometers were unable to distinguish changes in soil moisture content at soil moisture tensions below 3 centibars. The soil moisture status in further line source trials will be monitored using TDR soil moisture sensors.

Water balance

Figure 3.8 shows the percentage of irrigation and rainfall collected in the lysimeters under the different irrigation treatments. The amount collected ranges from 80 per cent in the W2 irrigation treatment to 48 per cent in the W6 treatment.

Significant rainfall occurred towards the end of the trial during week 7 (40 mm) and again during week 8 (30 mm). Figure 3.9 shows the percentage of irrigation that was collected in the lysimeter up until week 7 prior to the rain. The percentage collected in the drier W5 and W6 treatments was less then 25 per cent.

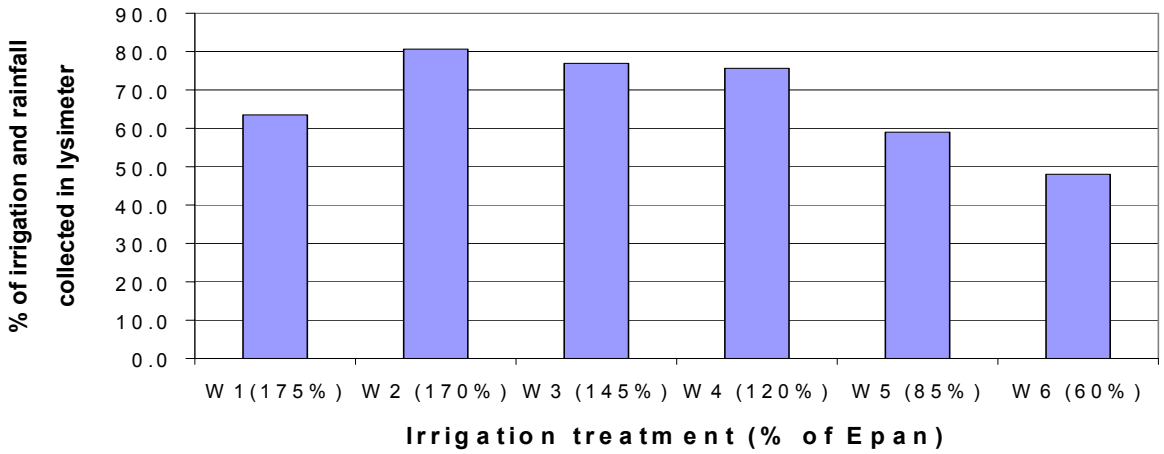

Figure 3.8. Percentage of irrigation and rainfall collected in the lysimeter for different irrigation treatments.

The water use efficiency when using optimum irrigation rates (100 per cent of Epan increasing to 140 per cent of Epan) was poor. To achieve maximum yield with this irrigation system and method of scheduling around 70 per cent of the water that was applied passed through the root zone. This percentage is likely to be higher on grower properties for two reasons. Firstly, irrigation uniformity on vegetable growers properties on the Swan Coastal Plain is poor (Milani, 1992) and as a result growers over irrigate the wet areas of the wetting pattern in order to supply sufficient water to the drier areas. Secondly, few if any vegetable growers on the Swan Coastal Plain use any method of irrigation scheduling and they generally apply over 150 per cent of Epan throughout the crops life.

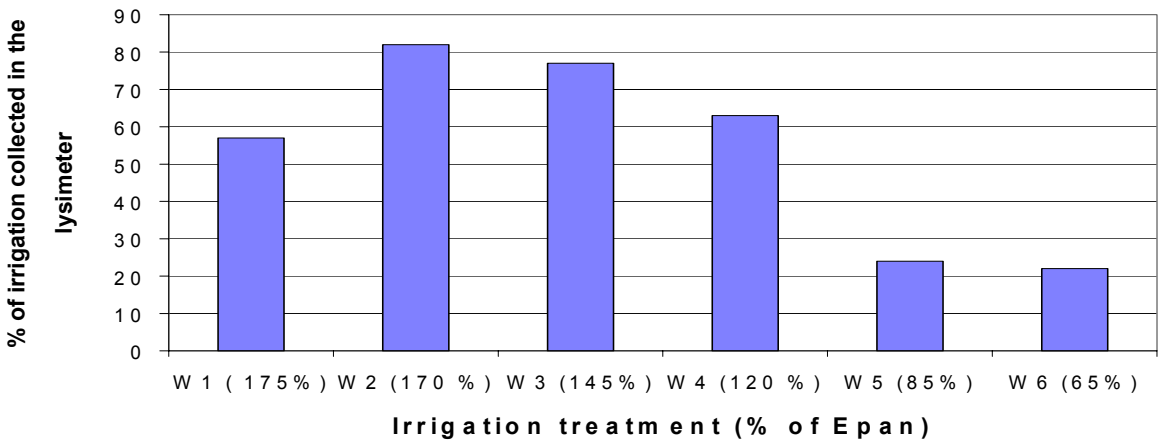

Figure 3.9. Percentage of irrigation collected prior to rain in the lysimeter for different irrigation treatments

Comparing Figure 3.9 with Figure 3.8 shows the effect of rainfall. The water use efficiency of the lower irrigation rates (W5 and W6) was good prior to rainfall. However even if these rates could be used, such as with more efficient drip irrigation, heavy leaching rain is common over at least seven months of the year. This would fill up the low water storage of the sand and readily push water and nutrient past the root zone.

Water used to irrigate vegetables on the Swan Coastal Plain is almost always obtained from the shallow superficial aquifer. Excess irrigation recharges the same superficial aquifer. Consequently poor water use efficiency does not greatly waste water reserves (except for

some evaporation losses), however the most significant consequence is the associated leaching of fertiliser and contamination of the groundwater.

Nitrogen balance

Figure 3.10 shows the amount of nitrogen collected in the lysimeters for each irrigation treatment when the N3 rate of fertiliser was applied (600kg/ha/crop). Around half of the applied nitrogen was collected in the lysimeters for the W1 to W4 irrigation rates. Low nitrogen loads were collected in the lysimeters below the W5 and W6 irrigation treatments. High levels of nitrogen are likely to remain in the soil below these plots (nitrogen uptake in the crop was low because the cabbages were small due to moisture stress). Wetting up of the soil profile prior to subsequent cropping and/or rainfall is likely to leach the majority of any residual soil nitrogen from the root zone making it unavailable for any following crop.

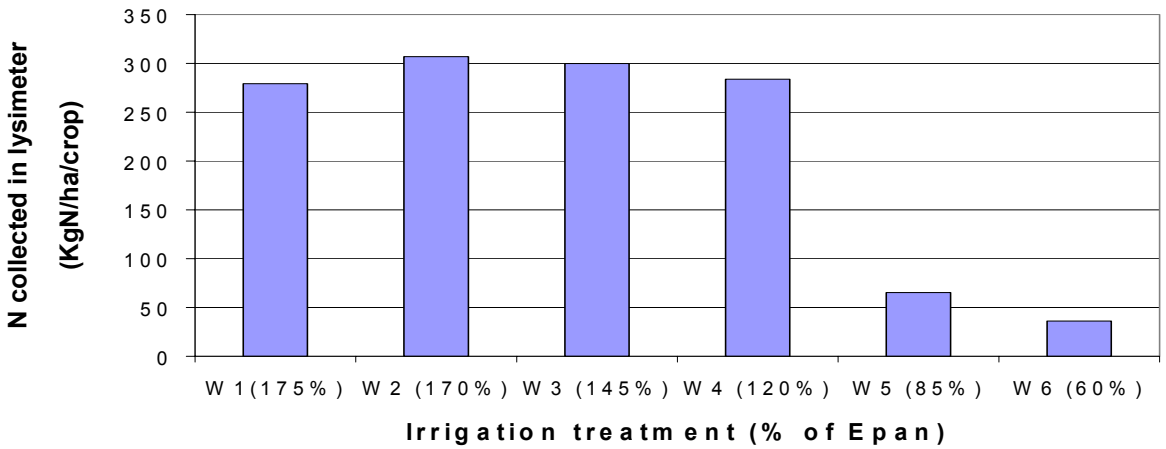

Figure 3.10. Nitrogen collected in each lysimeter for each irrigation treatment (N3 Fertiliser rate - 600 kg/ha/crop).

Figure 3.11 shows the total number of kilograms of nitrogen collected in the lysimeters throughout the trial when different nitrogen rates were applied under the W4 (120 per cent Epan) irrigation rate. The amount collected varied from 32 kg N/ha under the N0 plot to 270 kg N/ha under the N3 rate.

The nitrogen fertiliser rate required for 99 per cent of maximum yield (570 kg/ha/crop) and the nitrogen loss rate are high compared to other vegetable growing areas in the world (Lorenz and Maynard, 1988). Similar nitrogen loss rates were recorded on growers properties by Sharma (1991). On properties where large amounts of poultry manure are applied and /or where chemical fertiliser is applied via a non uniform method (fertigation or topdressing) then nitrogen loss rates are likely to be worse.

Lantzke (1997) found high nitrogen concentrations in the groundwater below horticultural properties on the Swan Coastal Plain. Nitrogen rich groundwater can contaminate drinking water and cause algal growth in surface water bodies. Irrigating with nitrogen rich groundwater can cause excessive crop growth.

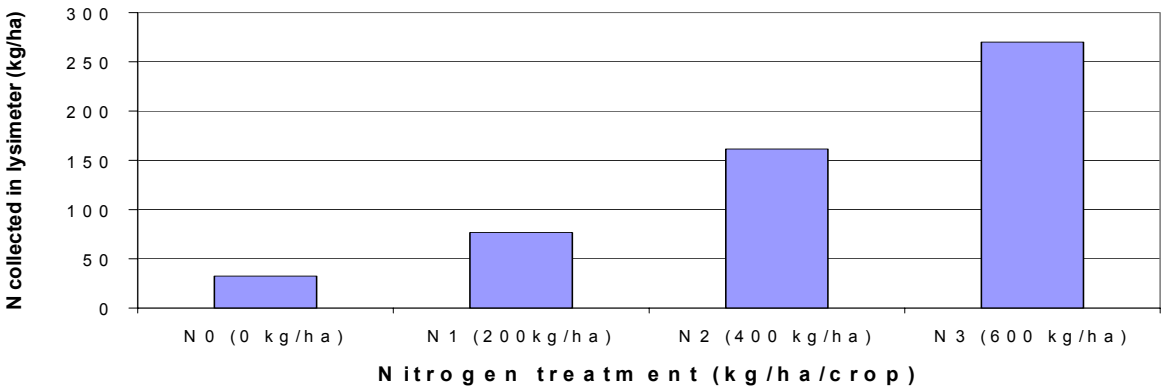

Figure 3.11. Nitrogen collected in lysimeters below different nitrogen treatments (W4 irrigation rate - 120 per cent of Epan).

The current approach to dealing with this problem on the Swan Coastal Plain is to exclude horticulture from the Public Water Supply areas and environmentally sensitive areas and to try and help growers reduce nitrogen loss though modification of existing management practices. More efficient fertilising and irrigation practices include developing crop factors and defining weekly nitrogen requirements (such as in this trial), post plant banding of nitrogen, daily fertigation and improving sprinkler uniformity. This approach number of has little or no chance of significantly reducing nitrates entering the ground water for the following reasons:

- The sands on the Swan Coastal Plain have a very low water and nitrogen holding capacity. The soil moisture content needs to be kept at or near field capacity in order to prevent stress of vegetable crops. To do this and not over water irrigation would need to be operated in pulses through out the day to maintain soil moisture just below field capacity. Sprinkler systems are generally not suitable for this because of interruption to agronomic practices and in some cases leaf disease.
- Heavy, leaching rainfall events are common on the Swan Coastal Plain. This combined with the low water holding capacity of the soil mean that any nitrogen in the soil will be leached by these events. In addition growers wet up the soil prior to planting. This will leach residual nitrogen left in the soil from the previous crop.
- Water is currently free and pumping costs represent less then 5 per cent of the total cost of growing a crop. Growers are prepared to over irrigate rather then carry out the time consuming task of scheduling irrigation.
- Soil moisture sensors are unlikely to be used by vegetable growers because of the time involved in installation and removal, the fact that they need to be read at least twice daily on these sands and because automation is not practical.
- Most vegetable growers produce a range of crops and have the same crop at different growth stages in immediately adjacent bays in their gardens. This makes irrigation scheduling difficult if not impossible.

Drip irrigation is an efficient method of irrigation and fertilising. Irrigation is applied precisely to the root zone and can be applied at frequent intervals without affecting agronomic practices such as spraying and harvesting. Fertiliser can be applied in small frequent intervals to the root zone which will reduce the chance of leaching due to rainfall. Crops can grow on drip irrigation using considerably less water and fertiliser. Drip irrigation is increasingly being used around world to grow good quality, high yielding vegetable crops. Adoption of drip irrigation by vegetable growers on the Swan Coastal Plain would depend on

the economics and management constraints of using such a system. This needs further investigation.

3.4 References

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3.5 Appendix 1

Appendix 1. Soil moisture tension graphs

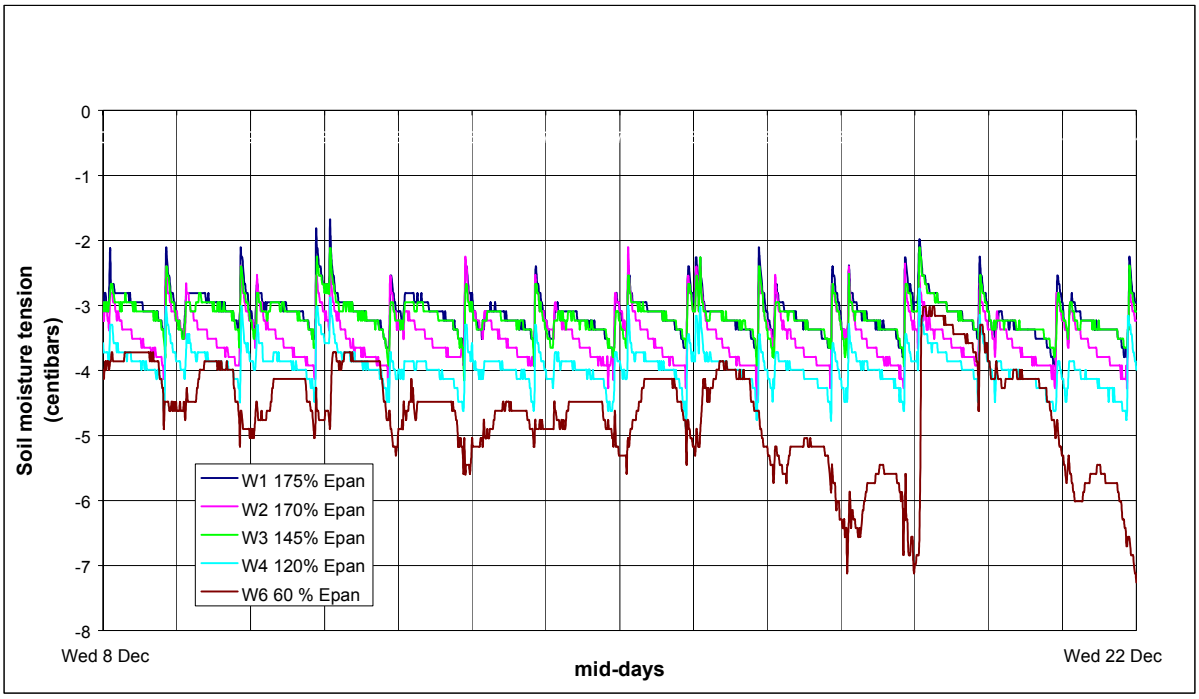

Figure A.1. Soil moisture tension 08/12/99 to 22/12/99 - 15 cm tensiometers.

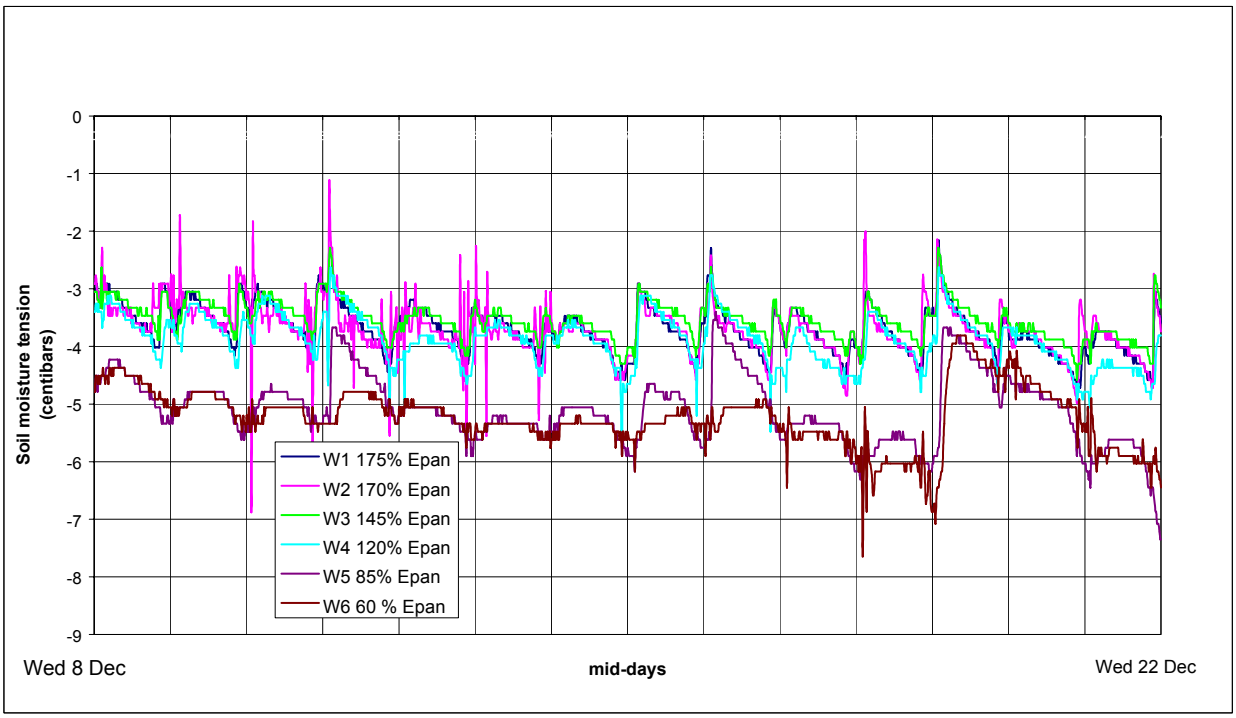

Figure A.2. Soil moisture tension 08/12/99 to 22/12/99 - 30 cm tensiometers.

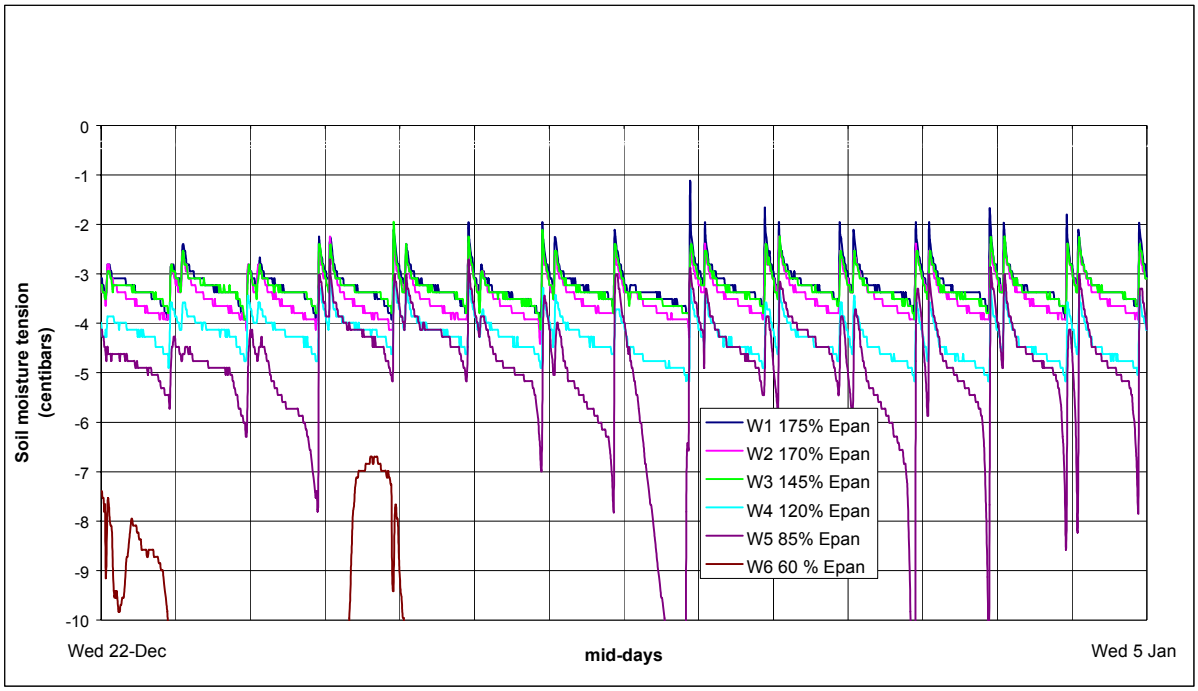

Figure A.3. Soil moisture tension 22/12/99 to 05/01/00 - 15 cm tensiometers.

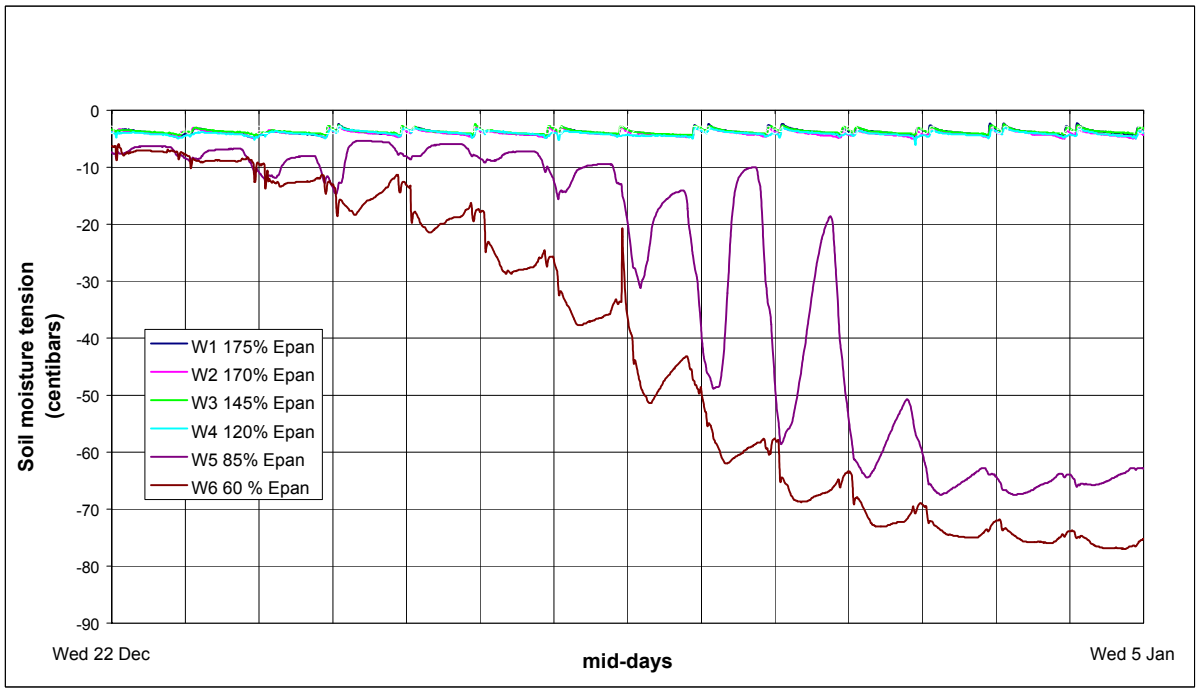

Figure A.4. Soil moisture tension 22/12/99 to 05/01/00 - 30 cm tensiometers.

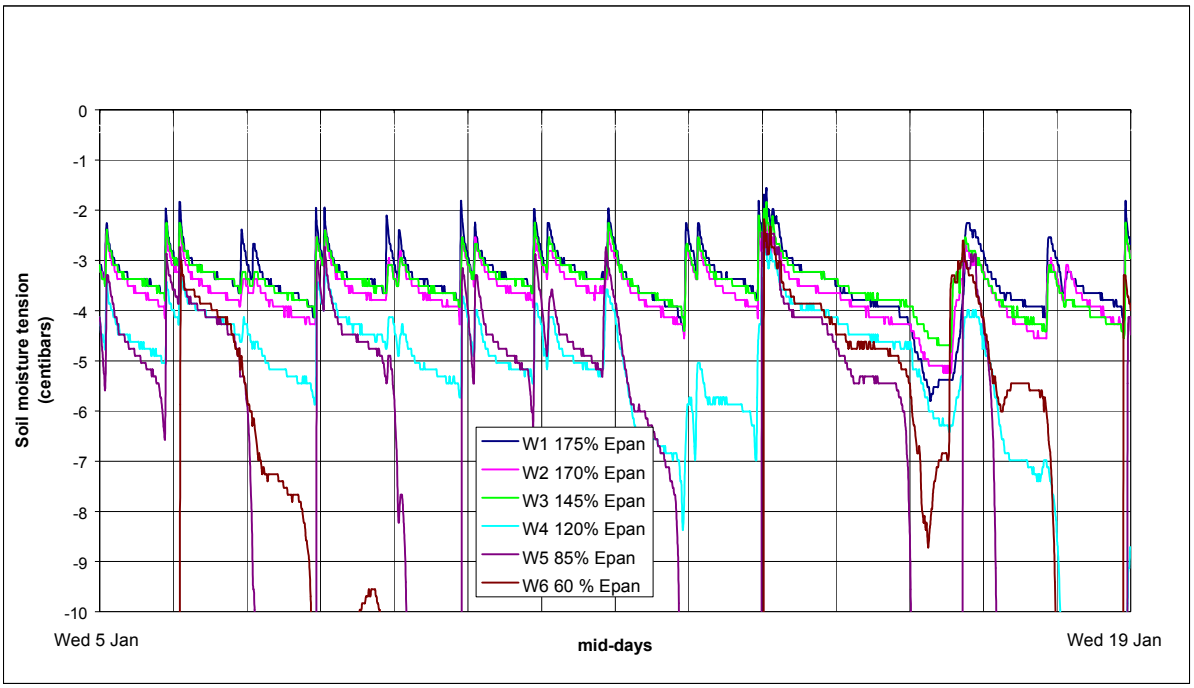

Figure A.5. Soil moisture tension 05/01/00 to 19/01/00 - 15 cm tensiometers.

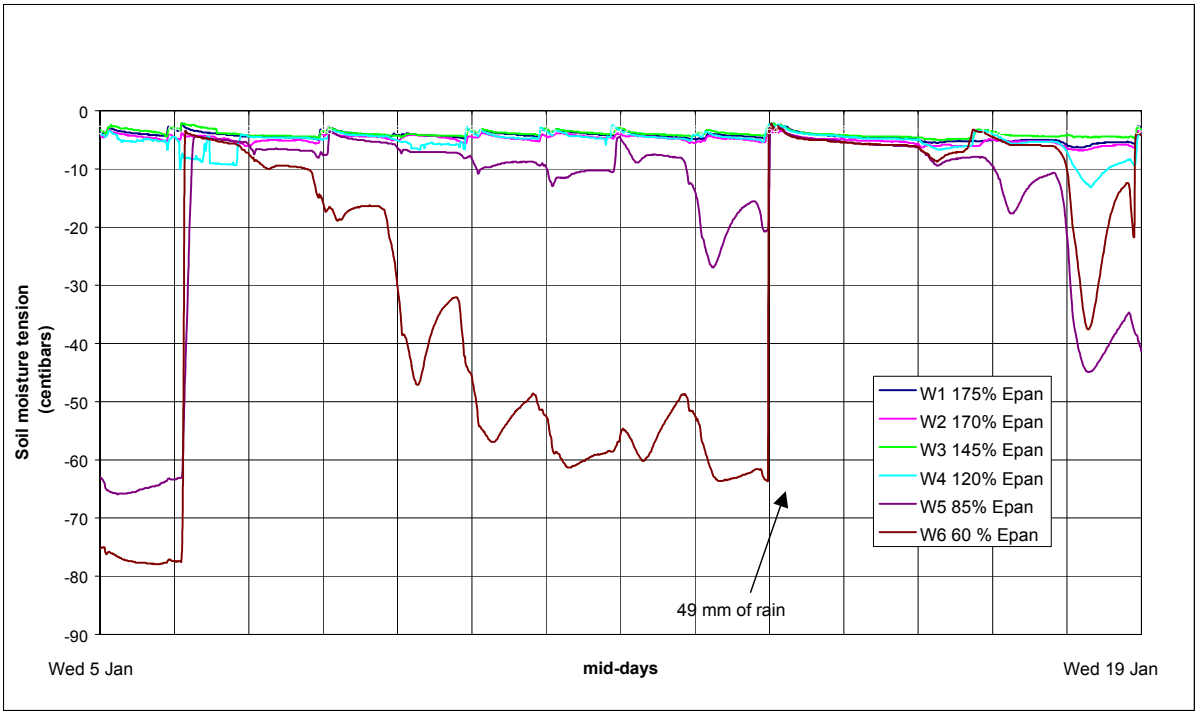

Figure A.6. Soil moisture tension 05/01/00 to 19/01/00 - 30 cm tensiometers.

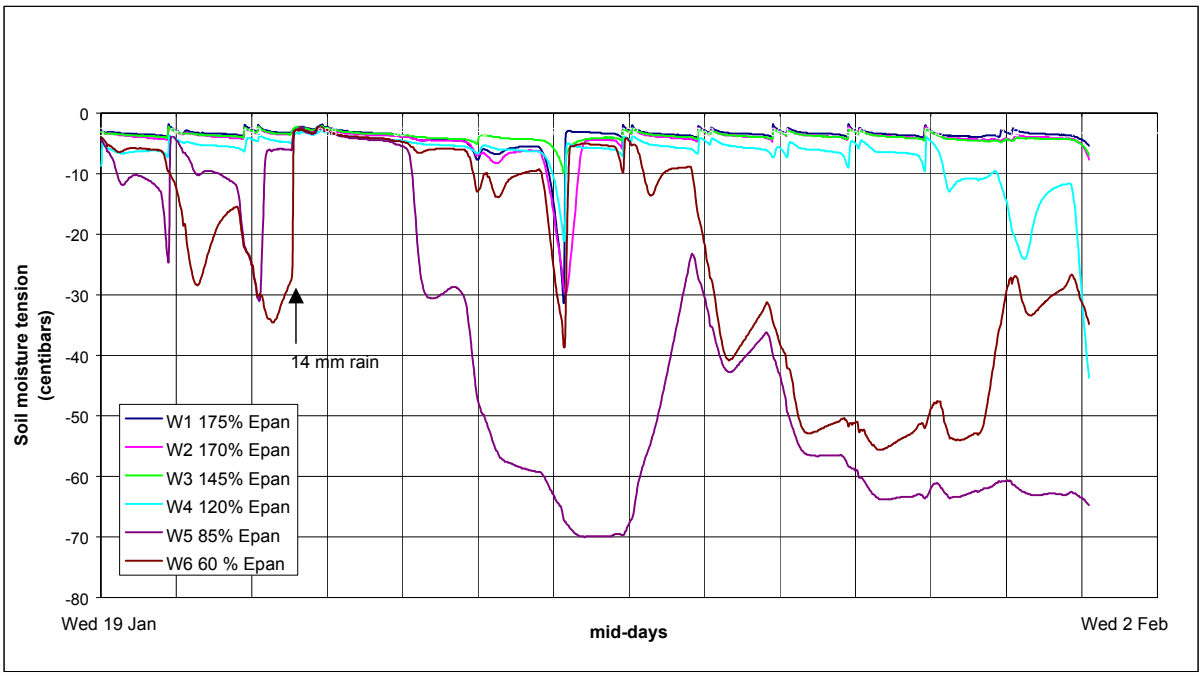

Figure A.7. Soil moisture tension 19/01/00 to 02/02/00 - 15 cm tensiometers.

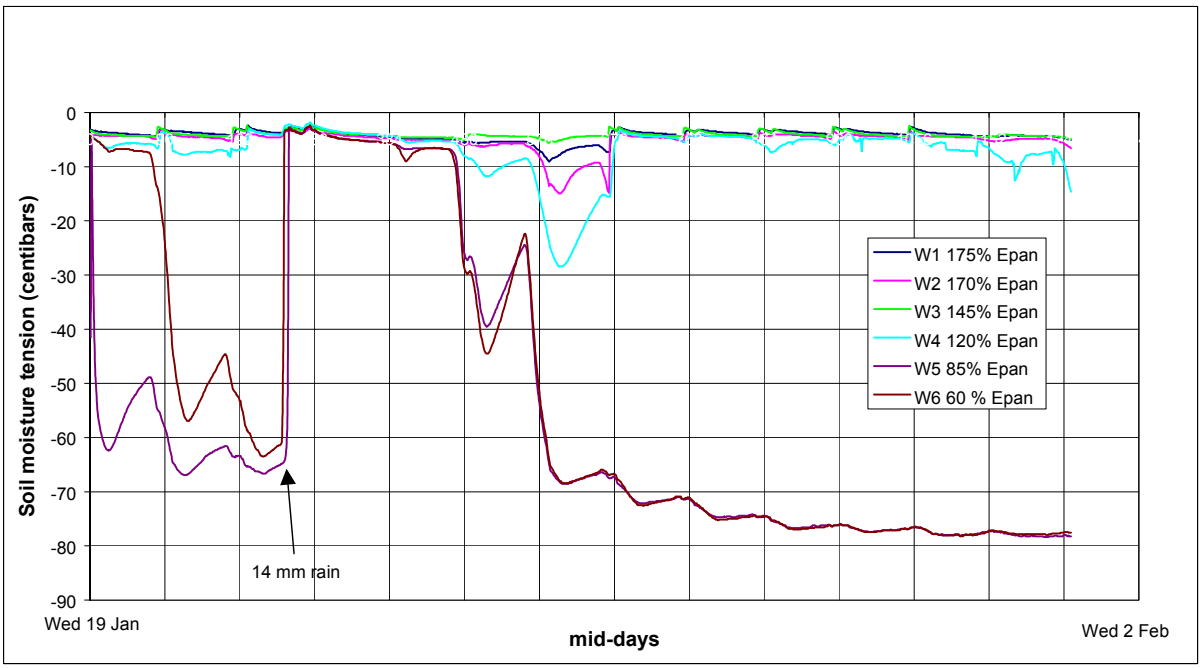

Figure A.8. Soil moisture tension 19/01/00 to 22/02/00 - 30 cm tensiometers.

4. BEST MANAGEMENT PRACTICES MANUAL FOR VEGETABLE PRODUCTION ON THE SWAN COASTAL PLAIN

What is a Best Management Practices Manual?

A Best Management Practices (BMP) Manual contains information on the best management practices known from research and practical experience and sets viable limits to inputs such as fertilisers and irrigation, so as to minimise environmental impact. They are written by growers with input from reseachers and development officers but they need to be regularly updated, and they deal with aspects of horticulture that have environmental and social impact/consequence.

What is their purpose?

BMP manuals provide up-to-date information on the management of land and water resources in order to:

- Promote and bring about the adoption and continuing development of sustainable horticultural practices.
- Define acceptable management practices to minimise future land use conflict and inform adjacent land users about the likely impacts from horticultural management practices.
- Promote self regulation of horticultural industries and avoid the need for regulation to be imposed on horticulture by government agencies.
- Provide accurate information on horticultural management practices that can be used by government agencies to:
  - assess the environmental risks and social impacts associated with horticultural development;
  - negotiate future changes to management practices with horticultural industries.
- Provide people new to horticulture with guidelines to establish and manage their properties.

4.1 BACKGROUND

Value of the vegetable industry

The vegetable industry was worth about $145 million to the State in 1992/93. The Swan Coastal Plain produces over 58 per cent of the State's vegetable production. Western Australia is also the leading State for vegetable exports in Australia. The major crops grown on the coastal plain include potatoes, carrots, cauliflower, lettuce, celery and onions.

Issues facing the vegetable industry

Environmental, social and health issues associated with horticulture affect growers and are of concern to the public and government agencies. This BMP manual aims to address these issues by outlining management practices that address these problems.

The major environmental, social and health issues that affect horticulture are:

Phosphorus leaching

Estuaries, rivers, lakes and wetlands on the coastal plain are often affected by algal blooms that choke the water, give off foul-smelling gases and kill fish and wildlife. These blooms are caused by an excess of phosphorus, with the major source being run-off and leaching from agricultural land.

Vegetable properties located on the poorer Bassendean soil types have been shown to readily leach phosphorus into the watertable. This phosphorus-rich water may ultimately reach surface water bodies causing algal blooms. There is very little chance of phosphorus leaching into the groundwater from vegetable production located on heavier soils, tuart sands or yellow Karrakatta sands provided there is reasonable depth to the groundwater.

Nitrate leaching

The sandy soils of the Swan Coastal Plain readily leach nitrogenous fertiliser. High nitrate levels, often in excess of the World Health Limit, are sometimes found in groundwater beneath horticultural properties. Drinking water with high nitrate levels can cause brain disorders, which especially affects infants. The Water and Rivers Commission wants to limit the expansion of horticulture over the Gnangara and Jandakot Public Water supply.

Flies breeding in poultry manure

The breeding of flies in poultry manure is a major concern for people living in the vicinity of vegetable production. A number of local authorities are becoming increasingly concerned over the escalation in fly breeding, particularly in rural and special rural areas. Council environmental health officers are enforcing the provisions of the *Fly Eradication Regulations* to, in some cases, prosecute persons for allowing fly breeding to occur on their properties.

Land use conflict

Conflict can occur between vegetable producers and their neighbours because of their farming activities. The most common example is special rural and urban land owners adjacent to horticultural properties complaining about noise, dust, odour and chemical hazards. Incompatible land uses should be kept apart through zoning or appropriate sub division decisions. This BMP manual will inform people buying property adjacent to horticulture of the likely activities that may be carried out.

4.2 BEST MANAGEMENT PRACTICE FOR VEGETABLE PRODUCTION

4.2.1. PROPERTY SELECTION AND FARM PLANNING

Property selection

- By selecting a suitable property and planning its layout the impact on the environment and the chance of land use conflict can be greatly reduced.
- When selecting a site choose a property which has a high capability for vegetable growing.
- Proposals for new horticultural developments in environmentally sensitive areas are likely to be refused or have restrictions set upon them. Environmentally sensitive areas include:
  - the Gnangara and Jandakot Public Water Supply areas;
  - areas of the Ellenbrook and Peel-Harvey Estuary catchment.
- The Department of Agriculture can provide advice on suitable areas for vegetable production.
- Local shires can also provide information on Rural strategies and town planning schemes and zones where horticulture is permitted.
- Before purchasing a property, check with the Water and Rivers Commission for groundwater availability and whether they have any environmental concerns about horticultural development in that area.

Soil types

The following section describes the major soil types on the Swan Coastal Plain and discusses the risk of phosphorus leaching and their capability for vegetable production.

Six major soil systems occur on the Swan Coastal Plain. These systems, and their associated soil types, are described below.

The Spearwood system

This system consists of a series of low rises extending in a belt parallel to and generally within 10 km of the coast. It includes the Cottesloe and Karrakatta soil associations. These are generally regarded as the good vegetable production soils on the Plain. Their slightly higher clay content results in better nutrient and water holding capacities than the poorer Bassendean sands. They occupy a milder climatic zone nearer the coast and generally have plentiful supplies of good quality groundwater at shallow depths.

Cottesloe association soils (Spearwood or Tuart sands) are generally red-brown in colour and have limestone within 1 m of the soil surface. Their pH is neutral to alkaline. The soils are well drained and have a good ability to retain phosphorus. These soils present very little phosphorus pollution risk.

Soils in the Karrakatta association are either yellow (yellow phase Karrakatta), or pale yellow (grey phase Karrakatta), with limestone at between 1 m and 10 m below the soil surface.

They have a pH between 6 and 7, are well drained and have vegetation consisting of jarrah, marri and banksia.

There is little phosphorus pollution risk on yellow Karrakatta soils because of their high retention ability, and depth to the watertable (7 m to 10 m).

The grey Karrakatta soils may present some pollution risk because of their lower phosphorus retention ability. The pale yellow colour indicates a lower concentration of iron and aluminium oxides which are important in holding phosphorus. However the watertable is generally deep (7 to 10 m), and in many cases the phosphorus retention ability increases with depth.

The Bassendean system

This system comprises low sandy rises and undulating sandplain with leached grey sands and many small swamps and depressions.

Demand for the expansion of horticulture on these soils is increasing, as high land prices and the lack of available land force growers to move from the more favoured Spearwood system.

Bassendean sands are predominantly situated in a belt between 6 and 8 km wide, through the centre of the Swan Coastal Plain. On their eastern edge they generally overlie the Pinjarra Plain soils. They are characterised by stands of banksia, Christmas tree, paperbark and the occasional marri.

The Bassendean system can be broken into three soil types (soil series).

- The Joel series

Flat, low lying areas containing grey sand over bleached white sand which sits on top of an iron organic pan (coffee rock). This pan generally occurs at depths from 50 cm to in excess of 2 m. The watertable is shallow and areas often become inundated during winter. These soils have little ability to retain phosphorus.

- The Gavin series

These consist of low rises and dunes of bleached pale sands usually found in association with the Joel series. These rises are about 2 m higher than the surrounding plain. The depth to an iron-organic pan is variable, ranging from about 50 cm to in excess of 5 m. The watertable is generally at depths below 2 m. These soils have a poor ability to retain phosphorus.

- The Jandakot series

This soil type often occurs on large dunes and rises immediately east of the Spearwood system. The soil profile consists of a grey sand over a white sand. This often grades into a pale yellow to yellow sand at variable depth. This soil is well drained with watertables 4 m from the surface.

Phosphorus is rapidly leached from the pale, sandy topsoil. Where a yellow subsoil occurs, soils of the Jandakot series have reasonable phosphorus retention ability.

The Vasse system

The Vasse system comprises low lying, poorly drained areas found on the beds of wetlands. They vary from black organic sands, peaty loams and black clays to true peats.

Once drained, non saline areas of the Vasse system are well suited to vegetable production. These soils were some of the first used for horticulture on the Swan Coastal Plain. Subsoil moisture enabled summer cropping of these swamps without irrigation.

Due to their organic matter these soils generally have a good ability to retain phosphorus, but high watertables mean that they may pose some phosphorus pollution risk.

The Pinjarra Plain system

The Pinjarra Plain consists of a flat, generally poorly drained, alluvial plain that stretches from the foothills west to the areas of Bassendean and Spearwood soils. Soils are variable and range from deep sandy duplex soils to red loams and grey clays.

The majority of the soils on the Pinjarra Plain are poorly drained throughout winter and are unsuitable for vegetable production (except for some summer cropping). The notable exceptions are the terraces of alluvial soils immediately adjacent to rivers and creeks. The phosphorus pollution risk from horticulture on the loamy soils of the Pinjarra Plain is low provided run-off does not occur. These soils generally have a high phosphorus retention ability.

The Ridge Hill Shelf system

The Ridge Hill Shelf system forms a narrow strip of undulating country, from 1 to 3 km in width, at the foot of the Darling Scarp. This system has an elevation above that of the Pinjarra Plain to the west and is well drained. The soils are most commonly yellow-brown or grey-brown sands to sandy loams over a yellowish brown clay subsoil. Ironstone gravel is often found throughout the profile. The native vegetation is jarrah and marri. Many of these soils are suitable for horticulture, however, the availability of groundwater may be limiting.

The soils of the Ridge Hill Shelf have a high phosphorus retention ability and do not present a phosphorus pollution risk provided run-off does not occur.

The soils of the Darling Scarp system have a high phosphorus retention ability and do not present a phosphorus pollution risk provided run-off does not occur.

The Quindalup system

The Quindalup system is comprised of beach dunes and foredunes immediately inland from the ocean. The sands are pale and calcareous with a pH of around 8.5.

These soils are unsuitable for horticulture due to their high pH, low moisture and nutrient holding ability and exposure to wind and salt spray. They do not present a phosphorus pollution risk.

Farm planning

Where possible choose the location of a future vegetable property away from neighbouring properties with urban, special rural or other land uses that may be incompatible with vegetable production. This may help avoid future conflict.

Buffers

Strips of vegetated land should be sited between horticultural properties and any adjacent drain, waterway or wetland. Buffer areas can also minimise spray drift.

Buffers of vegetation can prevent or reduce the amount of phosphorus entering drains, waterways and wetlands. The primary function of vegetated buffers is to stop surface water,

which may carry phosphorus rich sediment, from flowing directly into waterbodies. The vegetation acts to slow down waterflow causing sediment to settle in the buffer area. Water is then forced to pass through the soil before it enters the waterbody. Phosphorus dissolved in the water will be stripped as it moves through the soil, provided the soil has a good ability to retain phosphorus. Banks, ponds and other structures can also be used to intercept run-off and prevent sediment loss.

On Bassendean sands, which have poor phosphorus holding ability, phosphorus is lost via leaching to the shallow groundwater and lateral flow to adjacent waterbodies. Deep rooted species in the buffer area have some limited ability to remove phosphorus from the groundwater. In addition a proportion of the phosphorus in laterally flowing subsurface water is likely to be 'tied up' by the soil or layer of coffee rock under the buffer zone before it reaches the waterbody.

Vegetated buffer areas act as windbreaks which protect crops from wind damage. Reducing wind speed also improves sprinkler irrigation uniformity which reduces overwatering and associated leaching. A wide range of tree, shrub and grass species can be used in vegetated buffer areas.

The buffer areas should be planted and managed such that they contain enough vegetative matter throughout the year to prevent overland flow. It is essential that buffer areas have good ground cover at the end of autumn before the first winter rains.

Buffer areas can be used for commercial tree production. Fertilising of trees with phosphorus should be kept to a minimum and an earth bank built to prevent run-off entering the drain.

Table 4.1 indicates the width of buffer areas for major soil types on the coastal plain.

Table 4.1. Suggested minimum width of buffer areas from waterways or wetlands for established vegetable properties[A]

Soil system	Buffer width (m)
Spearwood system (Reddish and yellow sands)	20
Bassendean system Gavin and Jandakot sand Joel sands	 50 100
Pinjarra system	20
Ridge Hill shelf system	20
Vasse System	20

[A] The width of buffers suggested for the Spearwood, Pinjarra, Ridge Hill and Vasse system is 20 m because these soils have a good ability to hold phosphorus. Provided the vegetation in these buffers is properly maintained and no run-off flows directly through the buffer and into the waterway, then 20 m of buffer should be sufficient. The soils of the Bassendean system have a poorer ability to hold phosphorus. Larger buffer widths are set to account for this.

Earthworks

The major mechanism of phosphorus loss on the loamy and clayey textured soils on the Swan Coastal Plain is run-off or overland flow. On these soils phosphorus binds to clay and other small soil particles. These can be easily carried away by water run-off and into drains or adjacent wetlands. Run-off rarely occurs off sands.

Water run-off should not be allowed to leave areas used for horticultural production.

If water run-off occurs from the areas used for horticultural production build a small grade or level bank to intercept the flow. This nutrient rich water can be diverted away from drains or wetlands, or neighbouring properties and into settling ponds or vegetated buffer areas.

Windbreaks

The Swan Coastal Plain experiences windy conditions for much of the year. Wind causes physical damage and sandblasting of vegetable crops.

Strong winds greatly affect watering uniformity which can result in excessive watering and hence nutrient leaching in those areas.

Windbreaks should be placed at sites to protect crops and reduce overwatering and hence nutrient leaching.

Windbreaks can also reduce wind erosion of the topsoil. Crop yields are generally higher in areas protected by windbreaks because of the better micro-climate.

Windbreaks can consist of trees or can be made of synthetic materials such as Supamesh® and Paraweb®.

Windbreaks provide effective protection to a distance of about ten times the height of the structure. The length of the windbreak should be 10 to 20 times its height to reduce the effects of turbulence at its ends. Windbreaks should be between 40 and 55 per cent permeable; solid windbreaks create turbulence. Erect the windbreak at right angles to the dominant prevailing wind, i.e. north/south.

Trees are suitable for windbreaks, however the trees should be planted far enough away to prevent shading of crops. Tree species with extensive, shallow root systems which could draw water from the cropped area should not be used.

Cereal cover crops can be used to protect emerging vegetable crops from sandblasting. The cereals need to be killed with a herbicide before they begin to compete with the vegetables. Refer to Farmnote 24/84 'Building a synthetic windbreak', or contact your local adviser for information on types of trees, spacings, etc.

4.2.2 FERTILISERS

This section provides guidelines for phosphorus and nitrogen use on vegetables grown on the Swan Coastal Plain.

In most vegetable production, phosphorus is applied before planting as superphosphate, double superphosphate and/or as poultry manure. Additional phosphorus may be applied later as a single side dressing of superphosphate, with side dressings of poultry manure or with NPK-type fertilisers. Nitrogen and potassium are usually applied weekly throughout the crop's life either by topdressing or fertigation. Nitrogen and potassium are also contained in any poultry manure that is applied. Trace elements are generally applied every one to four crops, though some trace elements need to be applied more frequently depending on the soil type, soil pH and crop type.

Fertiliser nutrients can leach below the garden and build up in the groundwater. Irrigation with this water may add a considerable portion of the crops nutrient requirement.

- **Growers should analyse their bore water for its nutrient content.** The amount of nutrient applied through the irrigation water can be calculated and the fertiliser program adjusted accordingly (see Farmnote 2/95 'Nitrates in the groundwater beneath horticultural properties').

Phosphorus

- The amount of phosphorus required by any particular crop will vary with the soil type and previous fertiliser history of the area, as well as crop needs.

- The Karrakatta and Spearwood sands are able to retain significant amounts of applied phosphorus. Previous applications of phosphorus can build up soil phosphorus levels as phosphorus is bound or 'fixed' to iron and aluminium oxides in the soil.

- **For these soils use the soil test standards developed by Department of Agriculture, Western Australia.** Significant savings in fertiliser use can be achieved by soil testing to determine the most effective rate of phosphorus to apply.

- The pale Bassendean sands, which have a low iron content, have a poor ability to retain phosphorus. Phosphorus is readily leached past the root zone by rainfall and overwatering. **To reduce leaching, phosphorus should be applied in small, frequent applications, i.e. two or more times per crop. For example, apply split applications of superphosphate one pre-plant and one as a topdressing, or apply phosphorus post plant with NPK type fertilisers.**

- **Match phosphorus application rates with crop requirement.** Table 4.2 recommends upper limits of phosphorus application for commonly grown vegetable crops on a yellow Karrakatta sand. Trial results and field experience suggest that these rates are adequate to grow an economic crop.

Table 4.2. Upper limits of phosphorus for common vegetable crops grown on a Karrakatta sand

Crop	Yield (t/ha)	Status of garden	Phosphorus required (kg/ha/crop)	Phosphorus removed (kg/ha/crop)	Residual phosphorus (kg/ha/crop)
Cabbage	60	Established New	100 150	18	82
Carrots*	60	Established New	100 190	24	76
Cauliflowers*	30	Established New	100 150	25	75
Celery	100	Established New	130 220	31	99
Lettuce*	40	Established New	100 400	30	70
Onions*	60	Established New	170 500	27	143
Potatoes*	55	Established New	100 210	23	77
Pumpkins	30	Established New	100 180	20	80

Table 4.2. Upper limits of phosphorus for common vegetable crops grown on a Karrakatta sand (continued)

Crop	Yield (t/ha)	Status of garden	Phosphorus required (kg/ha/crop)	Phosphorus removed (kg/ha/crop)	Residual phosphorus (kg/ha/crop)
Rockmelons	30	Established New	100 140	19	81
Tomatoes	100	Established New	160 320	16	84

Assumptions and footnotes:

1. The rate of phosphorus required for new land is higher than that required for established land because there is no phosphorus 'bank' in the soil.
2. Rates will vary with soil type, variety and with the method and rate of irrigation. These rates assume a reasonably efficient irrigation system.
3. Soil test standards have been developed for crops marked with an asterisk (on Karrakatta sands only). If soil test information is available then disregard the figures quoted and use these standards.
4. Spearwood sands: Phosphorus requirements of crops grown on Spearwood sands may be about 25 per cent higher than those figures quoted for a Karrakatta sand. A higher iron content in Spearwood sands leads to a greater fixation of phosphorus.
5. Bassendean sands: Because of their low iron content, Bassendean sands do not fix phosphorus to any extent. A larger proportion of any phosphorus applied is available for plant use on Bassendean sands. The phosphorus requirements of crops grown on Bassendean sands may be significantly lower than those given for Karrakatta sands, provided phosphorus is applied in smaller, frequent applications. The Department of Agriculture Western Australia is currently investigating the phosphorus requirements of vegetables on Bassendean sands.

Nitrogen

- **Nitrogen is poorly held by all sandy soils of the Swan Coastal Plain.** Heavy rainfall and overwatering readily leach nitrogen from the root zone.

- **Nitrogen should be applied in small, frequent applications, i.e. at intervals of less than seven to ten days.** In doing so any leaching caused, for example, by heavy rain or overwatering, will be limited to the last small application. In addition, the concentration of nitrogen in the root zone remains fairly constant rather than rising and then falling, as happens when topdressing at lengthy intervals. Keeping the nitrogen concentration at a steady, adequate level enables even growth and produces better quality crops. The additional time required for more frequent fertiliser applications is generally compensated for by increased quality and yield and by the lower amounts of fertiliser required as less leaching will occur.

- **Irrigation has an important influence on the leaching of nitrogen.** Applications of water in excess of what the soil can hold infiltrate past the root zone, taking nitrogen with them. Overwatering and poor irrigation design are major causes of nitrogen leaching.

- **Plant analysis or sap testing should be used to determine the nitrogen status of crops.** Adjust nitrogen applications based on these results. Soil testing is of limited use for determining nitrogen rates.

- **Fertigation can allow for more frequent applications of nitrogen than topdressing.** The irrigation system should be uniform, otherwise uneven nutrient application rates will result. The irrigation system should be designed with enough flexibility to allow different fertigation rates to be applied to different crops or crops at different growth stages within the garden. Fertigation will result in increased nitrogen leaching if the soil is saturated (e.g. immediately after heavy rainfall) and more water must be added in order to fertilise via fertigation.

- **When plants are young it is better to place nitrogen fertiliser with 'droppers' immediately adjacent to plants rather than spreading it over the whole garden.** Crops which have developed a more extensive root system are better able to extract nutrients that are spread over the whole garden.

- **Match nitrogen application rates with crop growth stage.** Crops require lower rates of nutrients when they are young than when in mid-growth. However, because their root systems are smaller, nutrients should be applied in more frequent, smaller doses. Reduce nutrient application as the crop approaches harvest.

- **Do not apply high rates of poultry manure (> 30 m^3/ha) as this will result in soil nitrogen levels far in excess of what the plant can use, hence nitrogen leaching will occur.**[1] All nitrogen contained in poultry manure is leached within about four weeks of application. If no poultry manure is used or low rates are used, it is necessary to commence small, weekly applications of inorganic nitrogen fertiliser early in the crop's life.

- **Match nitrogen application rates with crop requirement.** Table 4.3 recommends upper limits of nitrogen for commonly grown vegetable crops. Trial results and field experience suggest these rates are adequate to grow an economic crop.

Table 4.3. Upper limits of nitrogen for common vegetable crops grown on sandy soils

Crop	Yield (t/ha)	Nitrogen required (kg/ha/crop)	Nitrogen removed (kg/ha/crop)	Residual nitrogen (kg/ha/crop)
Cabbage	60	500	164	336
Carrots	60	350	86	264
Cauliflowers	30	500	109	391
Celery	100	550	151	399
Lettuce	40	400	120	280
Onions	60	400	147	253
Potatoes	55	550	184	366
Pumpkins	30	350	107	243
Rockmelons	30	300	106	194
Tomatoes	100	650	148	502

[1] Except in new gardens where poultry manure is used as a soil conditioner to build up the moisture retention and nutrient retention ability of

Assumptions and footnotes:

1. These rates assume that nitrogen is topdressed or fertigated weekly. Trial results indicate that the rate of nitrogen fertiliser can be significantly reduced if applied in smaller, more frequent applications.
2. Rates will vary with variety, plant density, time of year, rainfall and method and rate of irrigation. These rates assume a reasonably efficient impact or butterfly irrigation system.
3. Crops grown on new land require slightly greater amounts of nitrogen than those on established land (due to lower soil nitrogen levels and a greater rate of leaching) because of their low organic matter levels.
4. The rates of poultry manure applied to 'build up' new gardens, will generally result in considerably more nitrogen applied than is actually needed.
5. Nitrogen is also recycled by cultivating in the remains of the previous crop. This may provide the next crop with some nitrogen.
6. Rates also include nitrogen from poultry manure.

Other nutrients

Other fertiliser nutrients used by vegetable growers are not known to pose a risk to the environment. Recommendations for individual crops can be obtained from the Department of Agriculture.

Cadmium is a toxic element that can contaminate food crops. It enters horticultural soils as a contaminant in phosphate based fertilisers and organic fertilisers. Use a phosphorus fertiliser other than superphosphate, e.g. double superphosphate.

4.2.3. IRRIGATION

- Before buying a property or expanding production, check with the Water and Rivers Commission that groundwater is available and if a water licence is necessary.
- Excessive irrigation on horticultural properties infiltrates past the root zone leaching nutrients. These nutrients may ultimately pollute groundwater.
- Nitrogen, is held weakly by all sandy soils of the coastal plain and is easily leached by excessive irrigation or heavy rainfall. Phosphorus is 'fixed' or held by most soils and is not readily leached, except for the Bassendean sands which have a low phosphorus retention ability.
- Proper design and efficient operation of irrigation systems are essential to reduce nutrient leaching.

Crop water requirements

- The aim of irrigation is to prevent crop moisture stress while keeping deep drainage to a minimum.
- The sandy soils of the Swan Coastal Plain have a very low water holding capacity. **To prevent moisture stress on sandy soils frequent watering is required** – up to three or more times per day for shallow rooted vegetable crops during the hot summer months. The volumes of water applied in each watering should be small; enough to fill up the soil profile but not cause excessive deep drainage.

- **Young crops, because of their smaller and less extensive root system require water to be applied in smaller, more frequent applications.**

- Watering of crops at night to take advantage of cheap electricity rates, results in increased nutrient leaching. The low water holding capacity of these soils means much of the applied water has drained away before the plants start using water – at daybreak. **Night watering on sandy soils should be restricted to the few hours before sunrise** except under some situations where frost control is required. **Night watering can lead to the development of some leaf diseases if conditions are conducive to development.**

- There are two methods that can be used to check whether the correct amount of irrigation is being applied.

Evaporation replacement

In this method the average daily evaporation rate for each month and a crop factor which takes into account the crop being grown, are used at the beginning of each month to determine how much water to apply for that month. The rate applied should be adjusted on days with atypical climatic conditions. See Farmnote 66/95 'Irrigating vegetables on sandy soils' for details on this method.

Soil moisture sensors

Soil moisture sensors are instruments which measure the water content of the soil. When the soil water content drops below a certain critical level, the irrigation can be switched on and then switched off when the root zone is full. There are a number of types of soil moisture sensors including: gypsum blocks, tensiometers, neutron probes and capacitance probes. However sensors can be unreliable on sandy soils. Refer to the Depatment of Agriculture's Farmnotes 26/90 for information on the operation of sensors.

Irrigation design

- **Irrigation systems must be correctly designed to ensure a good uniformity of irrigation over the crop.** If uniformity is poor, some areas of the property are overwatered to supply enough water to the drier spots. This not only represents increased pumping costs but results in water draining past the root zone and taking nutrients with it.

- If nutrients are applied through irrigation with poor uniformity, then some areas will receive excess nutrients while others receive insufficient nutrients. The irrigation system should be designed so that it has flexibility to allow different irrigation and fertigation rates to be applied to sections of the property with different soils, different crops or crops of different varieties or growth stages. Proper design is critical to the success of an irrigation system.

- When designing and installing a new irrigation system follow the criteria outlined in the Farmnote 30/92 'Design guidelines for fixed sprinklers and micro-irrigation systems'.

4.2.4 Poultry manure

Poultry manure is used as a fertiliser and soil conditioner on vegetable production. Poultry manure improves the organic matter level of the soil and increases the soils nutrient and water holding ability.

The breeding of flies in poultry manure is a major concern for people living in the vicinity of horticultural properties. The greatest level of fly breeding associated with poultry manure occurs when it is applied to the soil for crop production. Fly breeding may also occur when manure stacks become wet from either rainfall or from irrigation sprinklers. It may also occur in apparently dry, deep litter poultry manure, as soon as it is removed from poultry sheds.

Applying large amounts of poultry manure may cause nutrient pollution of the groundwater. Large applications of poultry manure result in soil nutrient levels far greater than what the plant can use as sandy soils have a poor ability to hold nutrients. For example all nitrogen contained in poultry manure is leached within about four weeks of application.

Poultry manure can be used in all shires on the Swan Coastal Plain from May 1 to August 31. Poultry manure cannot be used from September 1 to April 30 in designated areas (refer to *Health Department (Poultry Manure) Regulations, 2001*). Conditioned or pelleted poultry manure can be used during this period. For more information, refer to Raw Poultry Manure Infonotes, Department of Agriculture, Western Australia, (2001).

Storage and stockpiling

- In all situations and without exception, poultry manure heaps on grower properties must be located outside of the range of irrigation sprinklers.

- Check with your local authority for additional requirements such as the covering of stockpiles. These requirements can be expected to vary in accordance with situations and concerns facing local authorities.

Maximum rates

Poultry manure in all forms should not be applied at more than the following rates:

New garden:	*First year* – 50 cubic metres per hectare per crop to a maximum of 120 cubic metres per hectare per year. *Second year* – 45 cubic metres per hectare per crop to a maximum of 100 cubic metres per hectare per year.
Established garden:	30 cubic meters per hectare per crop with a maximum of 75 cubic metres per hectare per year. With strawberries, the maximum application rate is 50 cubic meters per hectare per year.

Application methods

Pre-plant applications should be immediately incorporated to minimum depth of 200 mm. Depending on the rate used, the crop and the age or freshness of the manure, it should be applied no more than 5 to 10 days before seeding or planting. This minimises nitrogen loss and it should be noted that the more complete the burial of manure, the better fly control will be.

Monitoring

For two weeks following the application of poultry manure clumps of manure in the soil need to be regularly monitored by checking for the presence of larvae. Poultry manure heaps should also be checked.

Managing crop residues in the paddock

After harvest of many crops, the remaining crop residue can be a source of fly breeding.

Incorporate this crop residue or trash within five days of completing harvest, to minimise this source of fly breeding. This also maximises the value of this material for improving the soil.

Crop refuse/waste disposal

Remove sources of potential fly breeding from around sheds and working areas. Dispose of this material, including all non-marketable plant material, in pits which can be covered daily with a minimum of 30 mm of soil. Another alternative is to spread the crop waste back onto the garden and hoe in or feed to stock.

4.2.5 PESTICIDES

Pesticides include fungicides, insecticides and herbicides. Horticulturalists, often use pesticides because of the intensity of farming and high crop value. The misuse of pesticides is of concern for two reasons:

- Contamination of surface and groundwater bodies affecting wildlife and/or the quality of drinking water.
- Exposure to toxic levels of the pesticide either to horticulturalists applying the chemical or to consumers as residues in horticultural crops.

The National Farm Chemical Users Training Program offers horticulturists an intensive one-day course in safe and more effective use of farm chemicals (contact the Department of Agriculture, Western Australia, Pesticide Branch).

Application

- **Read the label on the pesticide container carefully.** This will identify the toxicity of the chemical and also provide first aid treatment advice.
- Chemicals can only be applied to a crop if they are registered for that crop.
- Apply pesticides at registered or label rates.
- Apply pesticides according to frequency stated on the label.
- Harvest crops when the required withholding period for the chemical has expired.
- Prepare only enough chemical for immediate use.
- Calibrate spray equipment to maximise uniformity and effectiveness.
- Check that nozzles are not blocked or worn out.
- Avoid working alone when using a highly toxic chemical.
- If possible, spray pesticides with an enclosed pressurised cab with an approved carbon filter for removing vapour, and a particular filter for removing dust and mist.
- Avoid spraying in strong winds.
- It is desirable to keep detailed records of pesticide purchases and their use on crops.
- Ensure a tap or water source is located close by to clean up any spills.

Disposal of containers

- It is important to properly dispose of empty pesticide containers as they may contaminate waterways and soil.

- Read the label for disposal suggestions. Some manufacturers will recycle empty containers. For instance, metham sodium 'blue drums' are recyclable.
- Once a pesticide container is empty, rinse it out with water and pour contents into the spray tank. Rinse out another two times and empty contents into spray tank. The empty container will now contain very low levels of pesticide.
- Puncture empty metal containers and flatten them if they can't be recycled.
- Contact your local council about disposal methods for containers.
- **It is illegal to burn pesticide containers**.

Storage

Chemicals should be stored safely away so they do not contaminate other goods.

- Store pesticides in original containers, with labels intact.
- Keep pesticides away from fertiliser, seed or animal feeds.
- Store in cool, dry place, and if possible locked away in a safe place.

Wash down areas

Pesticide levels may build up in wash down areas.

- After completion of spraying hose down the inside of the tank and partially fill it with water. Spray this diluted pesticide/water mixture onto a farm track or into a sump area. Pesticide remaining in the tank should not be dumped into waterways.
- Concentrated residues should not be allowed to run to waste on the ground or into waterways.
- Use bleach or ammonia to create an alkaline solution which aids in the breakdown of most pesticides.
- Wash down protective clothing or dispose of, as appropriate.

Safety when using pesticides

- It is desirable for chemical users to undergo regular (annual) medical examinations.
- The pesticide label will indicate what type of protective clothing is necessary.
- The type of protective clothing required depends on the toxicity and concentration of the pesticide and the conditions in which it is used. Farmnote 99/88 - 'Protective clothing for pesticide spraying operations' - outlines protective clothing for pesticide spraying.
- Pesticides should be mixed in a well ventilated area.
- Avoid spraying in strong winds.
- Wash up after spraying, and especially before eating, drinking or smoking.
- Keep a first aid kit handy.
- Avoid contact with the skin, especially around the eyes.

Integrated pest management

For some crops, integrated pest management practices have been developed making vegetable producers less reliant on chemicals to control pests. Contact the Department of Agriculture for the latest information on IPM for your crop.

4.2.6 OCCUPATIONAL HEALTH AND SAFETY

All horticulturalists need to be aware of the Occupational Health, Safety and Welfare legislation of 1995. Producers should familiarise themselves with the Act, especially Section 19 which states that 'an employer shall, as far as practicable, provide and maintain a working environment in which employees are not exposed to hazards. For further information, contact the Department of Occupational Health, Safety and Welfare (phone (09) 327 8777).

4.2.7 WASTE MANAGEMENT

- Unmarketable product that remains in the field needs to be rotary hoed deep into soil to aid breakdown.
- Unmarketable product that has been harvested from the field needs to be taken to an open pit and buried with at least 30 mm of soil as soon as possible, or taken back to the field and rotary hoed into soil.
- Washing water or effluent from washing vegetables such as carrots needs to be diverted so it will not run-off into waterways
- Packaging materials – polystyrene, plastics and cardboard should be disposed of in a proper manner and in accordance with local authorities.

4.2.8 LAND USE CONFLICT

Urban and special rural areas are expanding into districts that were once used for horticulture and agriculture.

This leads to conflict between existing horticulturalists and their non-agricultural neighbours. Conflict between horticulturists and their agricultural neighbours can also occur.

- Non-horticulturalists moving into existing horticultural areas should be made aware of acceptable farming practices that may take place. These include:
  - noise from tractors, pumps, cool rooms, trucks and sprinklers that may occur at any time of the day or night;
  - the use of lights at night around sheds or on farm machinery;
  - smells originating from poultry manure, rotting vegetation and chemicals. It is often unavoidable that some spray drift will leave the property. This is acceptable provided the equipment is used according to its design and all necessary precuations are taken;
  - dust.
- At the same time, growers should be considerate of their neighbours. Discuss any farming activities that you believe may be of concern to your neighbours. An acceptable compromise may be reached. For example, make as little noise as possible near homes, especially at night and avoid spraying under strong wind if large amounts of spray drift blows onto neighbouring properties.

4.3 Acknowledgments

These guidelines were prepared on behalf of the vegetable industry, by officers of the Department Agriculture working in conjunction with members of the Vegetable Growers, Market Gardeners and Potato Growers Associations.

4.4 References

Lorenz, O.A. and Maynard, D.N. (1988). Knott's Handbook for Vegetable Growers. 3rd Edition. John Wiley and Sons, Brisbane.

Building a synthetic windbreak. WADA Farmnote 24/84.

Protective clothing for pesticide spraying operations. WADA Farmnote 99/88.

Irrigating vegetables on sandy soils. WADA Farmnote 66/95.

Soil moisture monitoring equipment. WADA Farmnote 26/90.

Design guidelines for fixed sprinklers and micro-irrigation systems. WADA Farmnote 30/92.

Table 4.4. Typical phosphorus retention indexes (PRI) of soil types found within the catchment

	Spearwood system			Bassendean system			Vasse system	Pinjarra Plain system	Ridge Hill Shelf system
Depth (cm)	1. Cottesloe sand (Spearwood sand)	2. Cottesloe sand (Spearwood sand[+])	3. Karrakatta sand (yellow phase)	4. Jandakot sand and Karrakatta sand (grey phase)	5. Gavin sand	6. Joel sand	7. Herdsman peaty loam	8. Pinjarra Plain soil	9. Ridge Hill Shelf soil
0	7	4	3	< 1	0	0	200	3-100	2
50		25					300		4
100	8	27	5	< 1	0	0	Watertable**		
150	14	Limestone		3		18-390 (Coffee rock)		Watertable	
200	Limestone	Limestone	6	3	0?	Watertable[x]			High
250	Limestone	Limestone	22	4					
300	Limestone	Watertable		5	0?				
> 800	Watertable		Watertable	Watertable	Watertable				Watertable

[+] Flats with grey sand over limestone at shallow depth. Adjacent areas seasonally inundated.

[x] In winter the watertable rises above this coffee rock layer.

** The watertable occurs near or close to the surface during the winter months.

Note: This table gives typical PRI values for each of the major soil types. Considerable variation may occur from site to site. For example in some cases an iron-organic matter pan with a PRI greater than 30 may occur in the subsoil of the Jandakot and Gavin sands.

5. TECHNOLOGY TRANSFER

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Gupta, K. L., (2001). Evaluating Sprinkler Performance Under Windy Conditions. Talk delivered at Irrigation Expo 2001, seminar organised by Irrigation Association of Australia, Perth, Western Australia, 16 October.

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Gupta, K. L. and Lantzke, N. (2000). Sprinkler Design Proves A Winner, Countryman Horticulture, Western Australia, Perth, 2 November.

Lantzke, N.C., Gupta, K.L., Deyl, R., Shimmin, T. and Calder T.C. (in preparation). 'The effect of wind speed and direction on sprinkler uniformity'. Department of Agriculture, Western Australia.

6. RECOMMENDATIONS

- A scientific paper on the sprinkler testing component of this project be submitted to an internationally recognised journal.
- This report be widely circulated to sprinkler manufacturers and distributors, and research and development organisations which have an interest in sprinkler design and uniformity.
- The economics of installing a more uniform sprinkler irrigation system be compared with installing a cheaper, less uniform system that has higher operating costs.
- The report 'The effect of wind speed and direction on sprinkler uniformity' be made available to growers in hard copy and via the Western Australian Department of Agriculture Web site.