Measuring the Effect of Altitude on the Radius of a Sprinkler

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Abstract

During a sprinkler "cross testing" project with the French the same sprinklers had a 1,5m longer range according to our tests compared to those of the French. Many possibilities were proposed as a reason for this difference.

At the end it seemed that it could be ascribed to the difference in altitude between the two test stations and a way had to be found to ascertain the exact relation between altitude and the range of a sprinkler.

A special mobile test bench was built and the same tests on the same sprinklers under the same conditions, except altitude, were done at our test labs in Silverton and the Hydraulic lab of the University of Stellenbosch.

The test method, apparatus and instrumentation that were used are described in the paper as well as some of the results that came out of this exercise.

Introduction

During a sprinkler "cross testing" project with the French it came out that for the same sprinklers there was a 1,5m difference in their range as measured by our tests compared to the tests of the French (Figure 1, [1]). This raised a lot of concern on our side because with the test facilities that the ILI Hydrolabs have it is impossible to make such a large error. Many possibilities were proposed as a reason for this difference. In the past it showed with the Floppy sprinklers that it has something to do with the natural vortexes of the earth. The Floppy sprinkler oscillates and turns at its natural frequency. When the turning direction of the Floppy was changed to anti-clockwise it had a longer range in the northern hemisphere. This was checked for sprinklers by modifying a sprinkler to turn clockwise or anti-clockwise at the same speed. (This was important because the turning speed of a sprinkler also has an effect on its range). Sprinklers though have a "forced" turning speed and it was found that the difference in the ranges that were measured was only about 10cm which also could be an experimental error for that matter.

The real reason was never thought of and it only came to my mind all of a sudden one day that the altitude at which a test is done must have something to do with it: for the French the altitude is 186m and for the ILI Hydrolabs it is 1345m above sea level. To verify this a special mobile test bench was built and the same tests on the same sprinklers under the same conditions, except altitude, were done at our test labs in Silverton and the Hydraulic lab of the University of Stellenbosch.

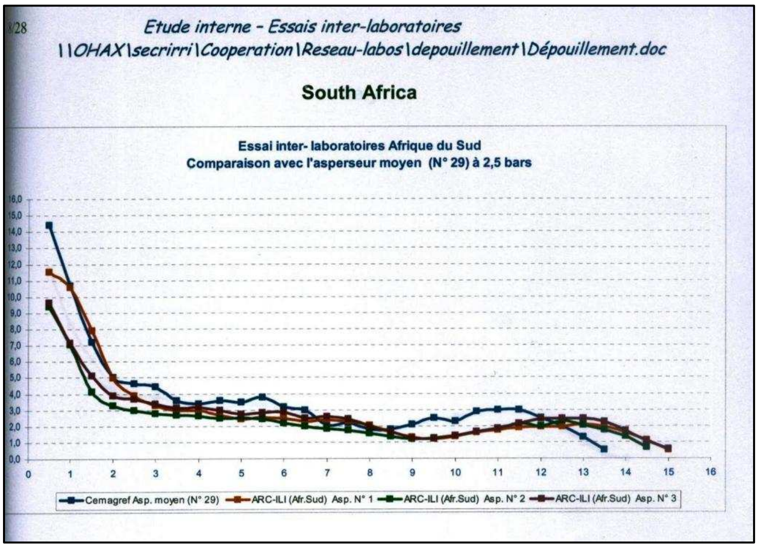


Figure 1: Comparative test results in the Cemagref (France) report [1]

Factors that affect the range of a sprinkler

There are many factors that have an effect on the range of a sprinkler and to be able to verify one factor only, all the rest have to be kept constant. These factors are the following:

- The nozzle size of the sprinkler
- The pressure at which it operates
- The height at which it is mounted
- The speed at which it rotates
- Whether it is standing upright or not
- And last but not least, the altitude at which it operates. This factor was *never* thought of before!

Fortunately many of these factors can be eliminated fairly easily. If the same sprinkler is used with the same nozzle size at the same height and operated at the same pressure in an upright position, most of the factors are kept constant. Even the turning speed is then catered for and thus the only variable that is left can be examined namely the altitude at which it is operating.

This is all very easily said and done if one wants to compare your own test results, but if you want to compare it with the results of other test stations over the world, all these factors come into play again and it is necessary to know what the effect of each of these factors are before it will be possible to make comparisons. About nine countries participated in the "cross testing" program and my intention was to get a relation between the altitude and the range of a sprinkler and to see if the tests done by the other countries also fall in this relation. This would be a very good check for this relation. This was achieved with the mobile test bench that was built and the tests that were done at Pretoria (altitude 1345m, figure 2) and Stellenbosch (altitude 118m, figure 2). The internet program Google Earth [2] was used to measure these altitudes as well as the altitudes of the other tests stations that were used in the comparison. Unfortunately most of the sprinkler test laboratories in the world are at a low altitude which means that most of the sprinkler data that exists in the world is only applicable for such conditions and it will be shown in the paper what the implications of it are in practice. This also put a limitation on the number of test laboratories that I could use for my comparison.

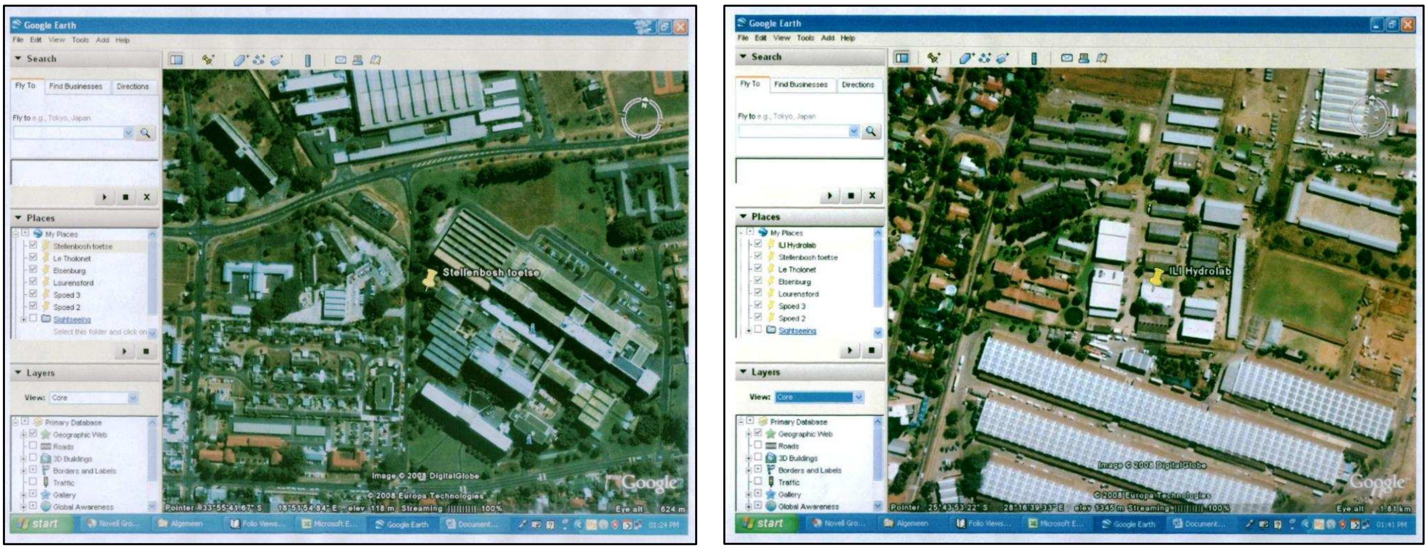


Figure 2: The Stellenbosch (left) and Pretoria labs (right) where the tests were done [2]

In the “cross test” program all the participants were supplied with the same model sprinkler and equipped with the same nozzle size. All participants also had to test the sprinklers at the same pressure. This eliminated two of the factors. The fact that the same sprinklers, nozzles and pressures were used also ensured that the turning speed of the different sprinklers would be the same. It is assumed that the sprinklers are mounted upright in the test benches and thus the only factors that did vary between the participants were the mounting heights and the altitudes at which the sprinklers were tested. The mounting heights could not be prescribed because the participants had to test the sprinklers identical to the way they usually test sprinklers and the mounting height is not the same on the different test benches of the participants.

In the past tests were done to find the relationship between the mounting height and the range of a sprinkler. The result is shown in figure 3.

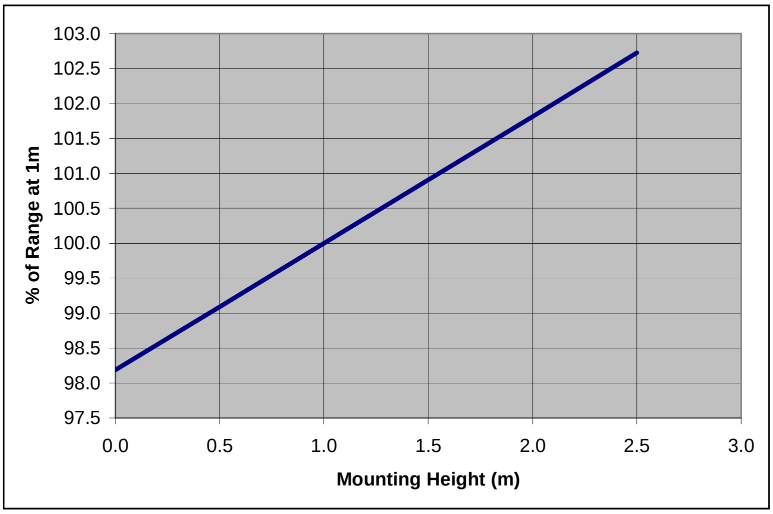


Figure 3: Sprinkler mounting height and range relationship

This result was used to adjust the ranges of other test labs where the mounting heights differed from that of our test bench.

Another factor appeared out of thin air when the sprinklers were tested on the mobile test bench and those results compared with the test results on the permanent solid state test bench of our test lab. These results are shown in figure 4.

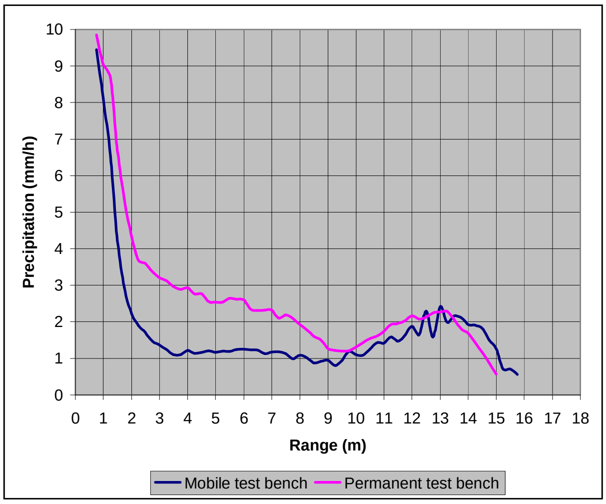


Figure 4: Comparison of the sprinkler test results on the mobile and permanent test benches

According to the mobile test bench the sprinklers have even a longer range! This result was very puzzling until it was found what the reason for that was. In figure 5 it can be seen that the mobile test bench is mainly made out of plastic. The result is that there is a high degree of flexibility in the construction of the test bench and it was observed that when the water from the sprinkler was projected into the air that the “head” of the test bench would momentarily bend backwards. When the water of the sprinkler is emitted into the air the sprinkler is thus not upright but bended backwards. As a result of that the water is emitted at a larger vertical angle and in the process the range is increased. Because of the fact that this error is a constant though, the tests that are done with the mobile test bench can be compared directly with each other, but when they are compared with the results of other test benches a correction must first be made according to figure 4.

Figure 5: Construction of the mobile test bench

The mobile test bench

In figure 6 the components of the mobile test bench can be seen. It consists mainly of two parts: the test vessel and the instrumentation. The test vessel is made up of the sprinkler cover on top (at such a height that the sprinkler is mounted at a height of 1m above the rain gauges), the control valves with the pressure sensor and flow meter (figure 5), the water reservoir basis and the pump which is protected by a filter at its inlet. Under the instrumentation fall the three digital panel meters (pressure, flow rate and mass), mass sensor, timer and seventy rain gauges.

Figure 6: Components of the mobile sprinkler test bench

The pressure gauge indicates the pressure at which the sprinkler is operating and is adjusted with the control valves to the exact test pressure needed, the flow meter measures the flow rate through the sprinkler and its reading is consolidated at the end of the test with the water that was measured by the rain gauges to check the accuracy of the test. The timer is used to let the test run for exactly two hours (see test procedure later on). The pump supplies the pressure (300 kPa) and flow rate for the sprinkler (about 1500 l/h).

Water is supplied via a hose pipe from a tap. Inside the top of the reservoir a ball valve is installed to maintain a constant water level in the tank which is necessary for the pump to be able to supply a constant pressure to the sprinkler throughout the duration of a test. The excess water that is released by the sprinkler inside the cover circulates back to the reservoir via the four “pipe legs” of the sprinkler cover (the sprinkler is mounted on the centre pipe). Facing the rain gauges a narrow slit (about 1cm wide) is made in the sprinkler cover where the water that is measured in the rain gauges exits.

While the standard tapered rain gauge is good enough for field evaluations of irrigation systems the calibrations on these gauges are not very accurate. Differences of up to 20% have been found between different makes of these gauges. The calibrations are also not very fine as can be seen in figure 7. For the purpose of the research that we wanted to do more accurate readings were necessary. Also for the ease of reading the rain gauges and opposed to getting the readings from the calibrations of the gauges an alternative reading method was sought. It was also found that water droplets would cling to the sides of the rain gauges after a test as can be seen in figure 8.

Figure 7: The calibrations on rain gauges are not very fine or accurate

If a reading would be taken from the calibrations of the gauges it would not have accounted for those amounts of water although it is water that was caught by the rain gauge.

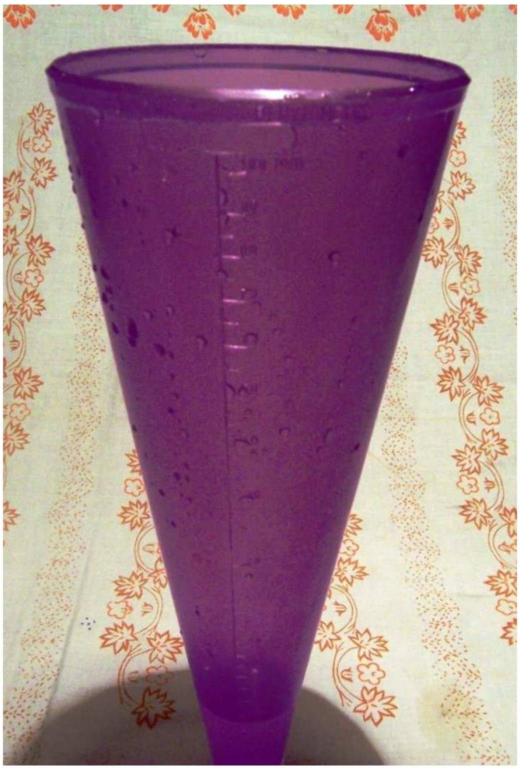


Figure 8: Water droplets clinging to the side of the rain gauge

Keeping all this in mind it was thus decided to weigh the rain gauges after the mass meter was "zeroed" with an empty rain gauge. The mass meter that was used measures to the nearest 10g but it was calibrated electronically to display directly the number of millimetres of "rain" in it. A number of empty rain gauges were "weighed" on it, but no difference could be picked up in this way between the gauges and it was accepted that for this purpose their masses are all equal so that whatever is displayed on the meter would only be the water that is in the gauge.

The test method

At first the three sprinklers that were used in the French tests were tested in Pretoria on the mobile test bench. The data from these tests were averaged and compared with their averaged data when they were tested on our standard test bench (the same data that was given to the French). For the French tests they were to be tested at 250, 350 and 450 kPa. Unfortunately the mobile test bench can only supply a maximum pressure of 300 kPa and therefore the sprinklers were tested at 200, 250 and 300 kPa on it. The pressure of 250 kPa is thus a common factor between the two test benches and only the data from these tests were used for comparative purposes in this study. The results of these tests are shown in figure 4 on page four of this document. There are a number of reasons why three tests are used. Usually a manufacturer specifies a working pressure for a sprinkler. To see if this is the best pressure we usually also do tests at 20% less and 20% more than this pressure and together with the specified pressure the sprinklers are thus tested at three pressures and the software that was developed to process the test data was written to accommodate three sets of test data at the same time. In this study the three pressures also gave the opportunity to see whether the same tendency occurs at other pressures than the "chosen" pressure.

After the Pretoria tests the mobile test bench was moved to Stellenbosch and the same tests were repeated there. Figure 9 shows the comparison between the Pretoria tests and the Stellenbosch tests and it is important to keep in mind that all test conditions were the same in the two places except for the fact that they are located at altitudes of 1345 and 118 m respectively.

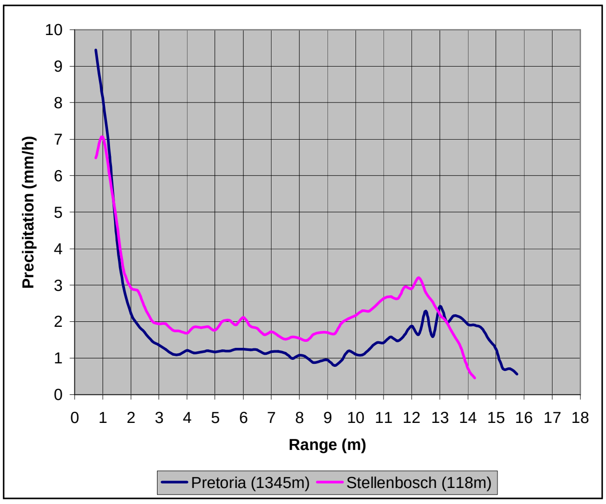


Figure 9: Difference in sprinkler range at 118 and 1345 m altitudes

In figure 9 the sprinkler has a higher average precipitation rate in Stellenbosch than in Pretoria. The reason for that is that the flow rate of the sprinkler is the same in both places. If the area below the graphs is extended 360^{O} around the sprinkler it is also theoretically equal to the flow rate of the sprinkler and this is compared with the reading of the flow meter during the test and if the test is done correctly these two values should be very close to each other. In Pretoria the wetted area is larger than in Stellenbosch because of the longer range and for the "volumes" of water to be the same in both cases the average precipitation rate in Pretoria must be lower.

The taking and processing of measurements

During a test we usually let a test run until a minimum precipitation rate of 0,5 mm/h can effectively be measured. In an effort to reach this and to make the measuring errors smaller a digital timer is connected to the pump of the mobile test bench and the test is left to run for exactly two hours. After that the rain gauges are "weighed" on an electronic mass meter (strain gauge type) which is calibrated to give a readout of the number of mm of "rain" in the gauge, starting with the gauge nearest to the sprinkler and continuing till the last gauge that contains a visible amount of water. These measurements are divided by two to get a number that represents the precipitation rate in mm/(one)hour and at the same time halving the measurement error.

The range of a sprinkler is defined as that distance from the sprinkler where the precipitation rate equals 0,3 mm/h. The common practise is to take the last two measurements at the far end from the sprinkler and to interpolate (or extrapolate) the distance where the precipitation rate equals 0,3 m/h. We found that this can lead to mentionable errors because in a sprinkler test those two readings are actually very uncertain as can be seen in figure 10. We therefore take the last five (or even more) readings at the end of the graphs and do linear curve fittings on them and from the equation of the fitting the position of 3,0 mm/h can be calculated.

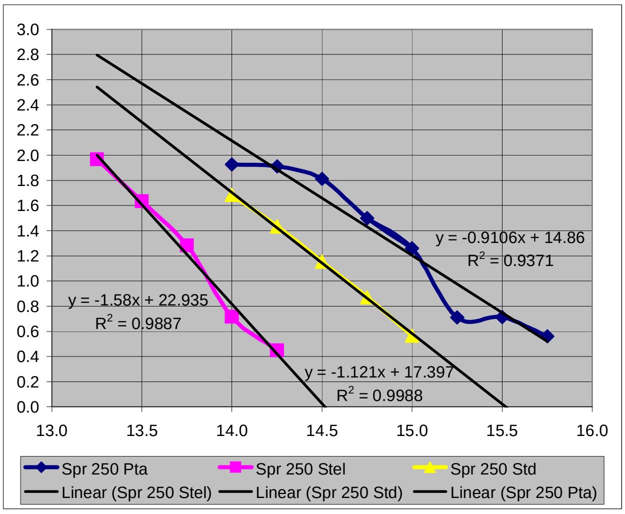


Figure 10: Finding the point of 0,3 mm/h with curve fitting equations

Table 1: Comparing the calculated ranges (at 0,3 mm/h) of the different tests

Test bench	Pretoria	Stellenbosch/France*	Difference
Mobile test bench	15,99 m	14,33 m	1,66 m
Mobile test bench compensated (fig. 4)	15,24 m	13,58 m	1,66 m
Permanent test bench	15,25 m	*13.62 m	1,51 m

The test data from three other countries were adjusted for the height of their sprinklers, their measured ranges calculated, their altitude measured with Google Earth and these results were plotted with the South African measurements and the result can be seen in figure 11.

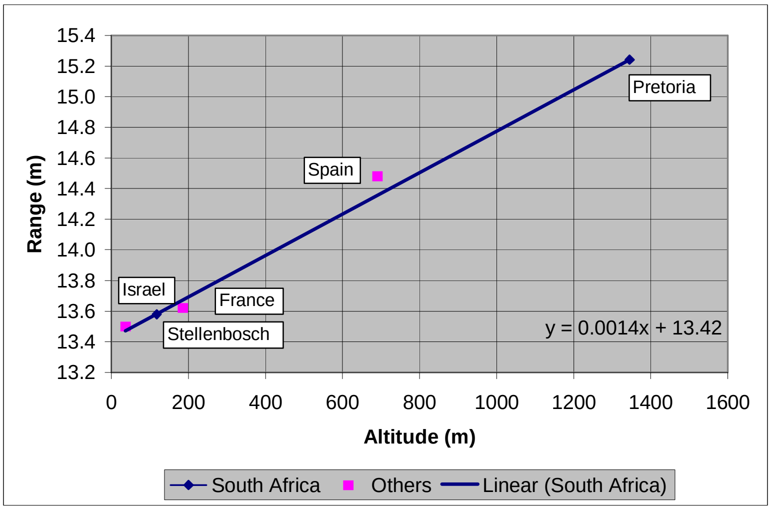


Figure 11: The South African results plotted together with the results from other countries

It was comforting to see that the results from the other countries also fell closely on the curve that was established in South Africa which proofs that the altitude do has an effect on the range of a sprinkler and that we have succeeded in finding out what the relation between the two factors is.

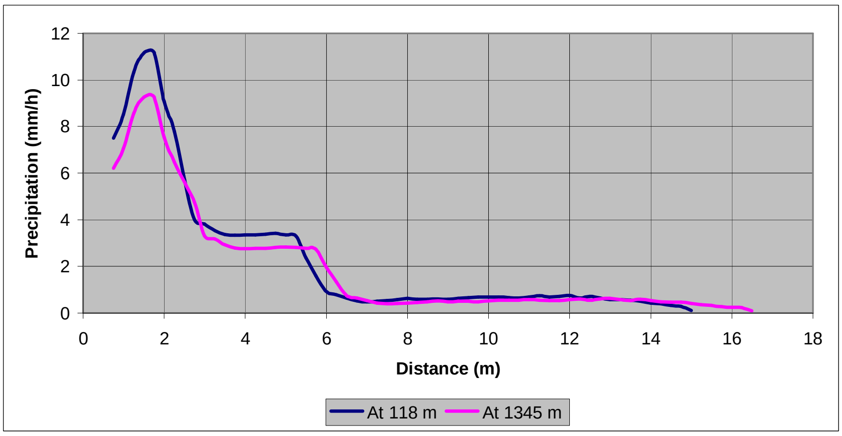
Practical implications

As was mentioned earlier that most sprinkler test data in the world was generated at low altitudes. If this data is to be used at higher altitudes it is not actually applicable any more and non-optimum sprinkler systems will be designed. The existing data can be theoretically extended to higher levels according to the relation that was found, but it can lead to errors and it would be better to have all sprinklers be tested at a higher altitude to see what their actual performances are.

To illustrate this three case studies were performed:
The distribution pattern of sprinklers can be divided in three main categories. These are:

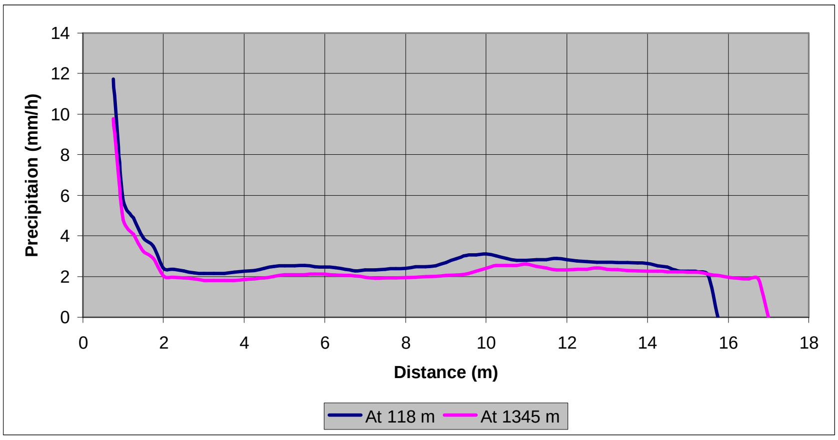
- Sprinklers with a triangular pattern where most of the water is deposited close to the sprinkler.
- Sprinklers with a flat or even pattern where more or less the same amount of water is placed over the full range and
- Sprinklers with a "toed" pattern where most of the water is placed at the far end from the sprinkler.

When testing a sprinkler the distribution pattern that is produced is used in a program that simulates different square and triangular spacings of identical sprinklers. The dimensions of these are in multiples of three because the quick coupling pipes that are used in these systems are made in multiples of three meters. This program will then super impose the contribution of each sprinkler on every square meter in the block and the uniformity of these values is calculated with two formulas: the Christiansen uniformity coefficient (CU) and the distribution uniformity coefficient (DU) and our norms in irrigation for these two values is that the CU must be above 84% and the DU above 75%. A third condition is that the average precipitation rate must be more than 3 mm/h. The program will select what are the widest spacings that the sprinkler can be used at and still comply with these conditions. In the following figures it will be shown what the effect of longer ranges for the three basic types of sprinklers are when it comes to their optimum spacings:



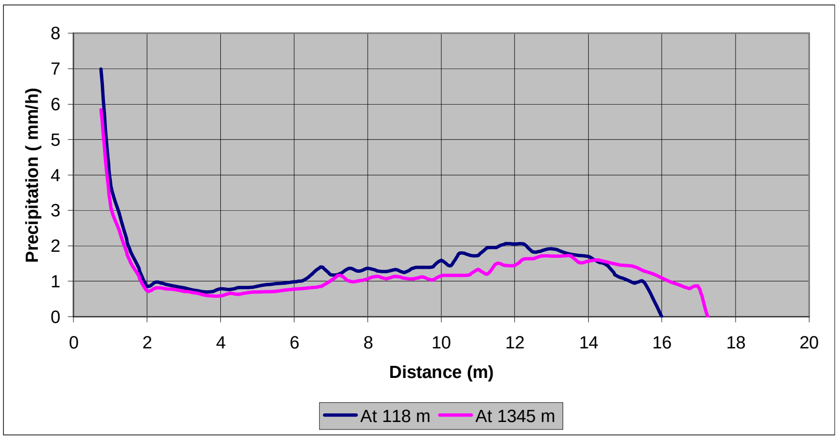
At 118 m:		
Type of spacing:	Rectangular	Area
Maximum sprinkler spacing:	18 m	162 m^2
Maximum lateral spacing:	9 m	
Average application rate:	3.2 mm/h	
Maximum radius:	15.25 m	
At 1345 m:		
Type of spacing:	Rectangular	
Maximum sprinkler spacing:	18 m	216 m^2
Maximum lateral spacing:	12 m	33 %
Average application rate:	2.7 mm/h	
Maximum radius:	16.75 m	

Figure 12: Sprinkler with triangular pattern



At 118 m:		
Type of spacing:	Triangular	Area
Maximum sprinkler spacing:	18 m	135 m^2
Maximum lateral spacing:	15 m	
Average application rate:	7.5 mm/h	
Maximum radius:	15.75 m	
At 1345 m:		
Type of spacing:	Triangular	
Maximum sprinkler spacing:	18 m	135 m^2
Maximum lateral spacing:	15 m	0 %
Average application rate:	6.3 mm/h	
Maximum radius:	17.25 m	

Figure 13: Sprinkler with flat pattern



At 118 m:		
Type of spacing:	Triangular	Area
Maximum sprinkler spacing:	18 m	108 m^2
Maximum lateral spacing:	12 m	
Average application rate:	5.3 mm/h	
Maximum radius:	16.00 m	
At 1345 m:		
Type of spacing:	Triangular	
Maximum sprinkler spacing:	18 m	135 m^2
Maximum lateral spacing:	15 m	25 %
Average application rate:	4.4 mm/h	
Maximum radius:	17.50 m	

Figure 14: Sprinkler with “toed” pattern

In figure 12 it can be seen that the sprinklers can be spaced wider resulting in an increase of 33% in the area that is covered and still giving an acceptable watering uniformity. This implies that a system that is 33% cheaper can be used by a farmer while still getting the same results. The same goes for figure 14 where the advantage is 25%.

Conclusion

With the mobile sprinkler test bench it was possible to establish a relation between the altitude at which a sprinkler is used and its range. It could be confirmed that a sprinkler has a longer range at higher altitudes with the result that sprinklers can be spaced wider without losing uniformity and which can result in noticeable savings on the cost of these systems.

References

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2. Google Earth: http//earth.google.com.