PERFORMANCE OF IRRIGATION SYSTEMS AND THE IMPACT ON WATER USE EFFICIENCY

FB REINDERS

ARC-Institute for Agricultural Engineering, Private Bag X519, Silverton, 0127, South Africa
E-mail: felixr@ing1.agric.za

Abstract

Irrigated agriculture is the largest user of water in South Africa and due to the pressure on the limited amount of water, the efficient use is of paramount importance. The environment in which irrigation farmers must function has also changed significantly in recent years. In particular, changes in legislation that regulates the use of water, impacts directly on irrigation practice. The National Water Act (Act 36 of 1998) provides for water resources to be developed and for water to be protected, utilised, conserved and controlled in a sustainable and equitable manner. This can only be achieved through effective design, maintenance and management of irrigation systems.

Through irrigation system evaluations in five sugar growing areas of South Africa by the Agricultural Research Council’s Institute for Agricultural Engineering, on behalf of the South African Sugar Association, the status of the system’s performance were determined.

Thirty-eight systems were evaluated which included Overhead (sprinkler and floppy), Centre pivot, Micro and Drip (Surface and Subsurface) systems. The areas that were targeted were Malelane, Komati poort, Umfolozi, Heat onville and Pongola.

Results from this project showed that the coefficient of uniformity (CU) for the dragline, floppy and centre pivot systems are $CU_d = 72\%$, $CU_t = 74\%$ and $CU_{cp} = 89\%$ with the accepted norm of 84\% or higher. The emission uniformity (EU) for the micro and drip systems was $EU_{md} = 72\%$ with the norm of 92\% and higher. The average low quarter distribution uniformity (DU) for the systems were $DU_d = 60\%$, $DU_t = 67\%$, $DU_{cp} = 83\%$ and $DU_{md} = 68\%$ respectively, with the accepted norm of 75\% and higher. The average application efficiency (AE) were $AE_d = 76\%$, $AE_t = 77\%$ and $AE_{cp} = 82\%$. The statistical uniformity (SU) for the micro and drip systems were $SU_{md} = 74\%$ with the accepted norm of 90\% or higher.

Although most of the systems performed lower than the accepted norms, it is within the range of what is normally found with in-field evaluations. The impact, however, is that with every 1\% drop in CU, the yield might drop by 2\%. The water use efficiency is also directly related to the application efficiency and the results showed that between 24\% and 18\% of the water were lost due to evaporative and wind drift losses. The percent of systems that had an acceptable DU were 100\% for centre pivot, 33\% for drip, 5\% for sprinkler, 0\% for micro and 0\% for floppy. Systems which were well maintained and correctly operated, generally had a high and acceptable DU.

The possible reasons for the low percentage of the systems that comply with the norms, could be a combination of incorrect pressures and spacings, worn nozzles, incorrect designs and climatic conditions with high wind speeds and temperatures.

Continued evaluation and maintenance of irrigation systems are imperative to keep the performance on a high level and to optimise water use efficiency.

Introduction

The process of efficient irrigation water management is to determine and control the rate, amount, timing and distribution of irrigation water so that the crop water requirements are met in a planned and effective manner. This not only depends on the correct technical and agricultural design but ultimately also on the standard of management and maintenance of the irrigation system.

Through irrigation system evaluations in five sugar growing areas of South Africa by the Agricultural Research Councils’ Institute for Agricultural Engineering, on behalf of the South African Sugar Association, the status of the systems performances were determined.

Thirty-eight systems were evaluated, which included Overhead (sprinkler and floppy),
Centre pivot, Micro and Drip (Surface and Subsurface) systems. The areas that were targeted were Malelane, Komatipoort, Umfolozi, Heatonville and Pongola.

Although most of the systems performed lower that the accepted norms, it is within the range of what is normally found with in-field evaluations.

Irrigation efficiency

Efficiency is difficult to define since it is a concept that represents the maximising of inputs.

![Irrigation efficiency diagram]

From figure 1 it can be seen that movement of water through an irrigation system, from its source to the root zone, is regarded as three separate operations: conveyance, system distribution and field application.

Conveyance is the movement of water from its source through the mains and submains or canals to the farm block off-takes.

System distribution is the movement of water through the distribution system or canals to the emitter outlets and on to the soil surface.

Field application is the movement of the water from the emitter outlets into the root zone of the crop.

With the evaluations, only the system efficiency was addressed.

Uniformity coefficients

There are several coefficients of uniformity of irrigation systems.

Coefficient of uniformity

To express the uniformity of how evenly the water is spread over the irrigated area the coefficient of uniformity (CU) is used. Uniformity coefficient values are determined by catching discharge from sprinklers on emitters in equally spaced cans and evaluating the catchments mathematically. Values for CU >84% is deemed satisfactory. The CU is an...
indicator of how the individual rain gauge readings deviate from the mean and it is calculated as follows:

\[
CU = 100 \times \left[ 1 - \frac{\sum R_i - m}{m \times n} \right]
\]

Where \( R_i \) = individual rain gauge reading (mm)
\( m \) = rain gauge mean reading (mm)
and \( n \) = number of rain gauges

For a centre pivot an adapted CU formula must be used which involves area weighing (multiplying by the area) each individual rain gauge reading to its representative section of the pivot area.

**Distribution uniformity**

Distribution uniformity (DU) is defined as a ratio of the smallest 25% accumulated depths in the distribution to the average depth of the whole distribution. Values of DU less than 60% are generally considered low and a value of DU greater than 75% is recommended. DU can be calculated as follows:

\[
DU = 100 \times \left[ \frac{m_{25}}{m} \right]
\]

Where DU = distribution uniformity (%)
\( m_{25} \) = mean of the lowest 25% of rain gauge readings (mm)
and \( m \) = mean for all the rain gauges (mm).

**Application efficiency**

The application efficiency (AE) is an indicator of water that is lost during the process of supplying water to the field due to evaporation and wind drift losses. It is defined as the volume of water applied to the surface divided by the volume of water exiting the sprinkler emitter. The following equation shows how the AE is determined in a CU test.

\[
AE = 100 \times \left[ \frac{m \times A}{V_s} \right]
\]

Where AE = Application efficiency (%)
\( A \) = plot area (m²)
\( V_s \) = volume exiting emitter during CU test (m³)

and \( m \) = mean application depth (mm)

A volume of AE > 75% is always strived for.

**Statistical uniformity**

The statistical uniformity (SU) for micro and drip systems is determined by using the coefficient of variation (CV). The formula is as follows:

\[
SU = 100 \left( 1 - CV \right)
\]

Where \( SU \) = Statistical uniformity (%)
and \( CV \) = Coefficient of variation

with \( CV = \sqrt{\frac{1}{1 - n} \times \sum_{i=1}^{n} (x_i - \bar{x})^2} \)

An SU of >95% is considered as excellent.
An SU of >85% is considered as good.

**Emission uniformity**

The emission uniformity is used to characterise the uniformity of micro systems and is given as:

\[
EU = \left( 1 - 1.27 \frac{CV}{\sqrt{n}} \right) \left( \frac{Q_{q}}{Q_{avg}} \right) \times 100\%
\]

Where
EU = emission uniformity
\( CV \) = manufacturers’ coefficient of variation
\( n \) = number of emitters
\( Q_{q} \) = average low-quarter emitter discharge (l/h)
\( Q_{avg} \) = overall average of emitter discharge (l/h)

**Methodology**

The environment in which irrigation farmers must function has changed significantly in recent years because of changes in legislation that regulates the use of water. The National Water Act (Act 36 of 1998) provides for water resources to be developed and for water to be protected, utilized, conserved and controlled in a sustainable and equitable manner.

The objective of the field evaluation programme was therefore to quantify the performance of the irrigation systems and to assist in improving the efficiency of water application by the irrigators. Evaluations were based on the American Society of Agricultural Engineers standards and expressed in the uniformity coefficients as mentioned.
The uniformity of each type of irrigation system is influenced by the following factors:

Sprinkler - pressure
- variation in pressure
- sprinkler spacing
- nozzle wear
- the water distribution pattern
- wind speed
- climatic conditions.

Centre pivot - pressure
- variation in pressure
- nozzle wear
- wind speed
- climatic conditions

Micro - pressure
- variation in pressure
- emitter characteristics
- manufacturing coefficient of variation
- filter system
- percentage blockages.

**Results and discussion**

A summary of all the results for the coefficient of uniformity (CU), emission uniformity (EU), low quarter distribution (DU), application efficiency (AE) and statistical uniformity (SU) are shown in Table 1 and in Figures 2 to 5. The systems in the different areas are identified by means of a letter “M” for Malelane, “K” for Komatipoort, “U” for Umfolozi, “N” for Nkwaleni and “P” for Pongola. The majority of the systems had a CU or EU, DU and SU lower than the accepted norms. Results from this project showed that the coefficient of uniformity (CU) for the dragline, floppy and centre pivot systems are CU<sub>d</sub> = 72%, CU<sub>f</sub> = 74% and CU<sub>cp</sub> = 89% with the accepted norm of 84% and higher. The emission uniformity (EU) for the micro and drip systems was EU<sub>md</sub> = 72% with the norm of 92% and higher. The average low quarter distribution uniformity (DU) for the systems were DU<sub>d</sub> = 60%, DU<sub>f</sub> = 67%, DU<sub>cp</sub> = 83% and DU<sub>md</sub> = 68% respectively, with the accepted norm of 75% and higher. Systems which were well maintained and correctly operated, generally had a high and acceptable DU. The average application efficiency (AE) were AE<sub>d</sub> = 76%, AE<sub>f</sub> = 77% and AE<sub>cp</sub> = 82%. The statistical uniformity (SU) for the micro- and drip systems were SU<sub>md</sub> = 74% with the accepted norm of 90% or higher.

In Tables 2 and 3, the percentage of systems that comply with the norms are shown. It must be pointed out that only a small amount of centre pivot, floppy and micro systems had been tested and it might not be a true statistical reflection of the performance of these systems in the different areas. All the centre pivots had an excellent CU and DU and none of the floppy systems exceeded the CU or DU norm. The possible reason for the low percentage of dragline systems that comply with the norms, could be the incorrect system pressure (of the twenty dragline systems which were tested only six of them operated within the acceptable pressure range) worn nozzles, incorrect spacings and the climatic conditions, where relatively high wind speeds prevailed during testing. The wind speeds varied from 1 to 11 m/s.

**Table 1: Summary of all the uniformity parameters by irrigation types.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dragline</th>
<th>Floppy</th>
<th>Centre Pivot</th>
<th>Micro &amp; Drip</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of systems tested</td>
<td>20</td>
<td>3</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>CU% or EU% (micro)</td>
<td>72</td>
<td>74</td>
<td>89</td>
<td>72</td>
</tr>
<tr>
<td>DU%</td>
<td>60</td>
<td>67</td>
<td>83</td>
<td>68</td>
</tr>
<tr>
<td>AE% or SU% (micro)</td>
<td>76</td>
<td>77</td>
<td>82</td>
<td>74</td>
</tr>
<tr>
<td>Design capacity (mm/day)</td>
<td>4.1</td>
<td>5.1</td>
<td>5.9</td>
<td>4.3</td>
</tr>
</tbody>
</table>

**Table 2: Percentage of dragline, floppy and centre pivot systems that comply with the norms.**

<table>
<thead>
<tr>
<th>Uniformity</th>
<th>Dragline</th>
<th>Floppy</th>
<th>Centre Pivot</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of systems</td>
<td>-</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>CU</td>
<td>84</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>DU</td>
<td>75</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>AE</td>
<td>75</td>
<td>60%</td>
<td>67%</td>
</tr>
</tbody>
</table>
Table 3: Percentage of micro drip systems that comply with the norms.

<table>
<thead>
<tr>
<th>Uniformity</th>
<th>Irrigation type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Norm (%)</td>
</tr>
<tr>
<td>No. of systems</td>
<td>-</td>
</tr>
<tr>
<td>EU</td>
<td>92</td>
</tr>
<tr>
<td>DU</td>
<td>85</td>
</tr>
<tr>
<td>SU</td>
<td>90</td>
</tr>
</tbody>
</table>

The wind also affected the floppy’s performance but not as much as with the dragline systems. In a research project by the ARC-ILI where impact sprinklers and floppy systems were evaluated the CU and DU values were in the same order as was found with this project. See Table 4.

Table 4: Results of research on impact sprinklers and floppy systems (WRC report).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Impact Sprinkler A</th>
<th>Impact Sprinkler B</th>
<th>Floppy</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU %</td>
<td>78</td>
<td>76</td>
<td>78</td>
</tr>
<tr>
<td>DU %</td>
<td>68</td>
<td>63</td>
<td>71</td>
</tr>
</tbody>
</table>

Figure 2: Performance of impact sprinkler systems
Figure 3: Performance of floppy systems

Figure 4: Performance of centre pivot systems
Figure 5: Performance of micro and drip systems

Figure 5 shows the performance of the micro systems (M28 and M29) and the drip systems (from M30 to P38). None of the micro systems exceeded the EU, DU and SU norms and only 11% of the drip systems exceeded the EU, 33% the DU and 22% the SU. Pressure variation and clogging is the mayor problem. Especially system K32 and U34 were severely clogged. The results of the uniformity of the micro and drip systems was similar to that of the other systems. This is contrary to the common belief that micro and drip systems have much higher uniformities than other irrigation systems.

Conclusion

Although most of the systems performed lower than the accepted norms it is within the range of what is normally found with in-field evaluations. It is however of the utmost importance that the systems should be properly maintained and operated within their specified design parameters to ensure optimal efficiency and operation of the system. The results showed that well maintained and correctly operated systems can achieve or exceed the uniformities which are considered reasonable and acceptable.

In order to conserve water resources, close attention must be paid to the performance of irrigation systems and continued evaluation and maintenance of irrigation systems are imperative to keep the performance on a high level and to optimize water use efficiency.

Acknowledgement

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References


